ESTONIAN UNIVERSITY OF LIFE SCIENCES

Institute of technology

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THE IMPACT OF ZNO NANO-ADDITIVES IN DIESEL FUEL ON THE EFFICIENCY PARAMETERS AND EXHAUST GAS EMISSION OF A DIESEL ENGINE

DIISELKÜTUSE ZNO NANOLISANDITE MÕJU DIISELMOOTORI EFFEKTIIVSUSPARAMEETRITELE JA HEITGAASIDE EMISSIOONILE

Master's thesis

Energy Application Engineering

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Maailma üha kiireneva arenguga on tekkinud suurem vajadus olla mobiilne. See tõttu on suurenenud vajadus sõidukitele, mis töötavad sisepõlemis mootoritega, mis kasutavad fossiilkütuseid, mis omakorda on kahjulikud meid ümbritsevale keskkonnale. Töö eesmärgiks oli uurida missugust mõju avaldab ZnO nanoosakene diiselkütusele. Antud töö raames on tehtud andmete kogumine internetist olemasolevatest uuringutest. Kõik töös käsitletavad katsed ning nende katsetulemused on teostatud Eesti Maaülikooli Tehnikainstituudi laborites. Katseandmeid analüüsides selgus, et 10mg tsinkoksiid nanoosakestel ei olnud märgatavat mõju diislikütusele. Andmete analüüsile antakse ka soovitusi järgnevateks uurimistöödeks.			
Märksõnad: Tsinkoksiid, nanoosakesed, diiselkütus, lisand			

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With the accelerating development in the world, there is a greater need to be mobile. As a result, there is an increased need for vehicles that run on internal combustion engines that use fossil fuels, which in turn are harmful to the environment. Nevertheless fossil fuels are necessary and increasing the efficiency of combustion engines has therefore become a priority. Therefore, the aim of the study was to investigate the effect of ZnO nanoparticle on diesel fuel on the fficiency of diesel motors. In the framework of this work, data has been collected from existing surveys on the Internet. All the experiments discussed in the work and their test results have been performed in the laboratories of the Technical Institute of the Estonian University of Life Sciences. Analysis of the experimental data showed that 10 mg of zinc oxide nanoparticles had no significant effect on diesel fuel. Nevertheless, reports in the literature have shown that nanoparticles increase the overall efficiency of combustion engines, therefore this research opens new perspectives for future works.			
Keywords: Zinc oxide, nanoparticles, diesel fuel, additive			

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INTRODUCTION

During the 21st century, nanotechnology has generated a rapid growth in industry, as it can be used in many technology fields to improve existing products and create new ones. Nanotechnology is already used in many fields like cosmetics, health and IT.

Nanofuels are fuels in which nanoparticles are mixed with regular fuel like diesel fuel, gasoline or bio fuel. Nanoparticles exhibit properties which their bulk counterpart do not have. For this reason, we studied the effect they may have on the efficiency parameters and exhaust gas emission of a diesel engine when combined with diesel.

The aim of the study was to evaluate the impact of ZnO nano additive in diesel fuel blend on the efficiency parameters and exhaust gas emission of a diesel engine.

The main tasks during this master´s thesis is to give:

- an overview of nanoparticles, their production and field of use;
- an overview of research work related to the use of ZnO in diesel fuel;
- preparation of a mixture of diesel fuel with ZnO additives and study its physical-chemical properties;
- a completion of engine tests with diesel fuel and diesel fuel with ZnO additives;
- test result analysis and evaluation for suitability for use in diesel fuel.

This topic is very important due to the new restrictions that will take place to limit emission from cars and also, because nanotechnology is now more regularly integrated in everyday products and technological fields. This study about nanofuels may help offer new solutions to make our everyday vehicles more environmentally friendly and economical. This would help keep our planet cleaner and make fossil fuels last longer since there are very limited resources on planet Earth.

The first chapter focuses on nanoparticles and their field of application. The first chapter introduces the different methods of nanoparticle synthesis. The second chapter describes the green synthesis of ZnO nanoparticles and blending of ZnO nanoparticles with diesel fuel. Chemical and physical property studies for test samples are presented in chapter 2, chapter 3 reports the performed Engine test results and their discussion.

I would like to thank Prof. Erwan Yann Rauwel, Prof. Protima Rauwel and Dr. Risto Ilves for their knowledge, guidance and support while writing this thesis. Big thanks to Estonian

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1. NANOPARTICLES AND THEIR FIELD OF APPLICATION

1.1. Nanoparticles and their applications

Nanoparticles are very small particles, their prefix „Nano" means that their size range is in 10^{-9}. Nanoparticle size is 1-100 nm. The comparison of different particles as a function of their dimensions are presented on table 1.[1]

Table 1. Particle sizes [1]

Particle type	**Particle diameter**
Atoms and small molecules	< 0.1 nm
Nanoparticles	1 to 100 nm
Fine particles	100 to 2500 nm
Coarse particles	2500 to 10000 nm
Thickness of paper	100000 nm

Nanotechnological major developmental phases occurred in the 21st Century, when in the beginning of 2000s scientist began using nanotechnology in commercial products. The growth of popularity in nanotechnology is based on electron microscopes, which helped the development of nanotechnology as one was able to visualize them and accurately determine their size and shape.

Its biggest impact has been in electronics and IT field. Two decades ago transistors used in electronic devices were 130 nm to 250 nm. However, in the 21st century scientists are now able to produce transistors as small as 7 nm, which highly increased computers processing power. In the year of 2016 *Lawrence Berkeley national Lab* demonstrated 1nm transistor which was able to work but was not consistent enough to be commercial, due to problems with leakage currents, as thinner the transistor, higher the leakage current. Thanks to nanotechnology, smartphones and computers are multiple times more powerful than in the 2000s. With nanotechnology we are able to create solid state devices, which can withstand folding, bending and stretching making devices more durable and more unique.

Nanotechnology has been extensively used in medicine. Human skin consists of three layers: epidermis, dermis and subcutaneous tissue. Cosmetic industry has found usage for nanotechnology because nano products penetrate human skin much faster, giving the cosmetic product deeper absorbing properties compared to non-nanoparticle products which only penetrate the dermis. According to studies, nanotechnology has shown potential in curing diseases such as sclerosis and thrombosis. The biggest medical breakthroughs are cancer treatment and rehabilitation area. Scientists have found a way to diagnose the probability of a patient developing cancer. Cancer treatment is very exhausting for patient, currently it is being treated by chemotherapy, which has many drawbacks like fatigue, hair loss, and anaemia. Scientist are working on a way to target cancer cells with drug carrying nanoparticles and destroy cancer cells. Such treatment could be extremely important in saving people from chemotherapy. [2]

While burning fossil fuels, exhaust gases are being discharged into the atmosphere separated into nature ozone layer. Nanoparticles added to fuel could make fuel burn much cleaner and could improve the engine efficiency factor. In addition, scientists are developing cables which are based on carbon nanotubes to reduce cable resistance and reduce voltage loss on high voltage lines. People are turning to renewable energies like solar panels which could generate electricity, considering the EU energy transition policy. Since solar panels have very small efficiency factor, scientists are focusing on making solar panels more efficient, cheaper and more affordable for regular consumers. [2]

1.2. Nano-fuels in diesel engines

The impact of nanoparticles on fuel and engine efficiency parameters have been studied in several works. [3], [4], [5] Since the current thesis is focused on Zinc oxide, therefore we are focusing on works where ZnO nanoparticles have been employed.

In the past nanoparticles have been added to the fuel as well. Studies have been carried out with cerium oxide (CeO), aluminium (Al) or cobalt oxide (CoO) nanoparticles. Test results showed that nanoparticles have good dispersion in fuel, giving the fuel better oxygen mixture and improving chemical reactions in the combustion chamber. Nanoparticles also improve the quality of exhaust gases by reducing HC, CO, smoke and CO_2 emissions. [3]

Nanoparticles in fuel show improvements in combustion, but it also could harm the environment when nanoparticles leave the exhaust. The focus on using nanoparticles in combustion engines, is to make combustion engines more environmentally friendly with increased efficiency. Also, the nanoparticles are produced by eco-friendly green synthesis routes that are cost-effective.

In the year 2020 there was a study published to show the effects of ZnO nano-additives on soybean diesel fuel at varying loads and compression ratios during the diesel engine characteristics test. The objective was to investigate zinc oxide (ZnO) nanoparticles in soybean biodiesel. The tests were made with scientific one-cylinder diesel engine. During the study, they added 25, 50 and 75 mg of ZnO nanoparticles to the biodiesel to find out which amount would make the best performance at the compression ratio of 18.5:1 and 21.5:1. Fuel mixtures were prepared with ultrasound processes variating nanoparticle and sodium sulphate amounts. From the results, it was found that biodiesel with ZnO nanoparticles increased fuels' properties, such as, calorific value and cetane number. 50 mg of ZnO nanoparticles in biodiesel increased fuels thermal energy by 20,59% and reduced fuel consumption by 20,37%. The cause of variation is ZnO catalytic feature on diesel fuel. Nanoparticles at the amount of 50 mg in the soybean diesel fuel separated heat from the engine as much as regular diesel fuel due to micro explosions in the combustion chamber. Hydrocarbons, carbon monoxides, smoke and CO_2 emission reduced by 30,83%, 41,08%, 22,54% and 21,66%. The amount of nitric oxide increased because of the increased amount of oxygen in the combustion chamber. [6]

1.3. Manufacturing of nanoparticles

In production of nanoparticles, one has to know material reaction conditions, which also determines the nanoparticle properties. Nanoparticle size, chemical composition, crystallinity and shape could be controlled by temperature, pH, concentration, chemical composition, surface modification and controlling of process.

In the production of nanoparticles there are two main methods: top-down and bottom-up. Top-down method indicates that material is being crushed and grinded to get into desirable size and shape. Bottom-up method indicates that nanoparticles are made with chemical processes to build up structures. On Figure 1.1 is brought out the processing methods top-down and bottom-up. [7]

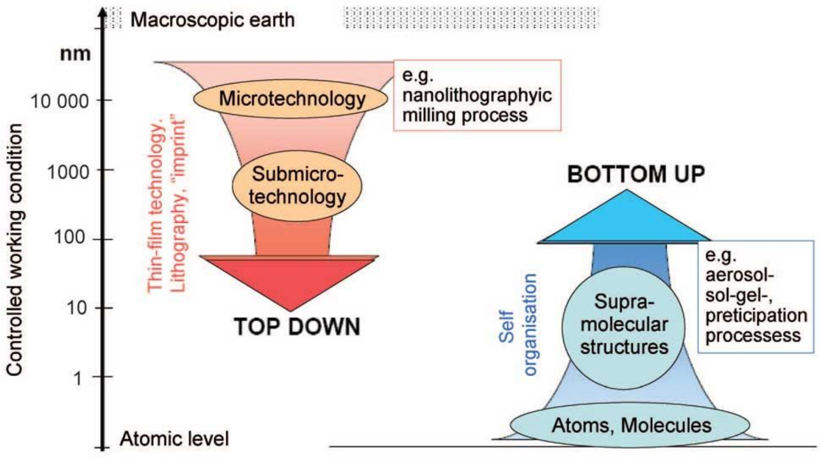

Figure 1.1. Nanoparticle processing methods. [7]

Top-down method for manufacturing nanoparticles

Top-down method indicates mechanical-physical treatment to produce particles. Traditional mechanical-physical method has several milling methods to produce nanoparticles (Figure 1.2). [7]

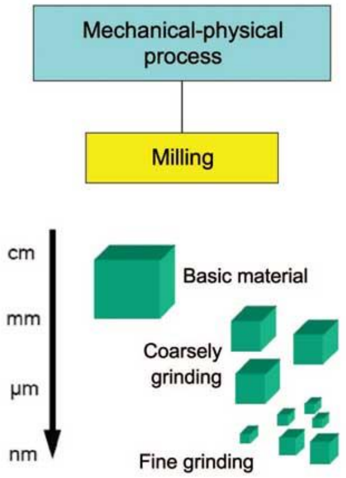

Figure 1.2. Top-down processing method. [7]

Mechanical material processing is mainly used with grinding method to crush microparticles. This approach in particular is used to process ceramic nanoparticles. To process metallic nanoparticles, metal oxides are used. Metallic nanoparticles are produced using high energy bearing grinding. These grinders are equipped with grinding environment which is made from wolfram carbide or steel. During the grinding method, thermal stress is released and this process is very energy intensive. However, grinding method does not have control over particle size and shape. [7]

Bottom-up method to manufacture nanoparticles

Bottom-up method is based on physical-chemical principle. During this process the end results have complex structures of molecules or atoms, also this process has better control over particle size range and shape. Bottom-up method also includes sol-gel and aerosol processes. Bottom-up method is referred on Figure 1.3. [7]

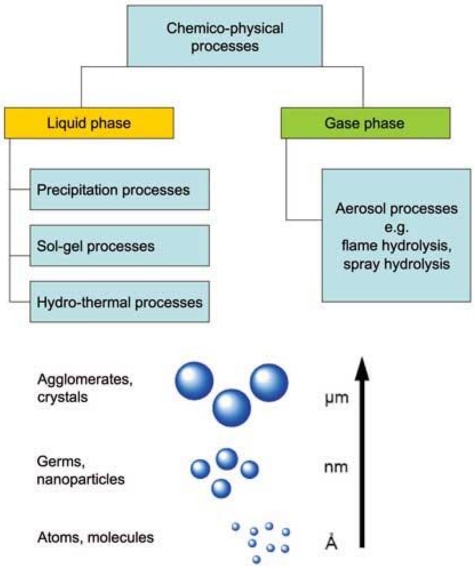

Figure 1.3. Bottom-up method. [7]

Gas phase processes

Nanoparticles are created from gas phase by using chemical or physical properties. Nanoparticles in solid or liquid state during the process are produced by homogeneous nucleation. The process is transmuting physical-chemical energy. During the process supersaturated gas, molecules or atoms are cooled with chemical reactions. This process is very energy intensive since high energy sources are used such as Joule heating, plasmas, sputtering, ion, laser beams or hot-wall reactions. Depending on kinetic, thermodynamic or flame reactors the atom or molecule processing is different. Particles can be formed by collisions or balanced evaporation to form molecular clusters or vice versa. Gas phase process is brought out on Figure 1.4. [8]

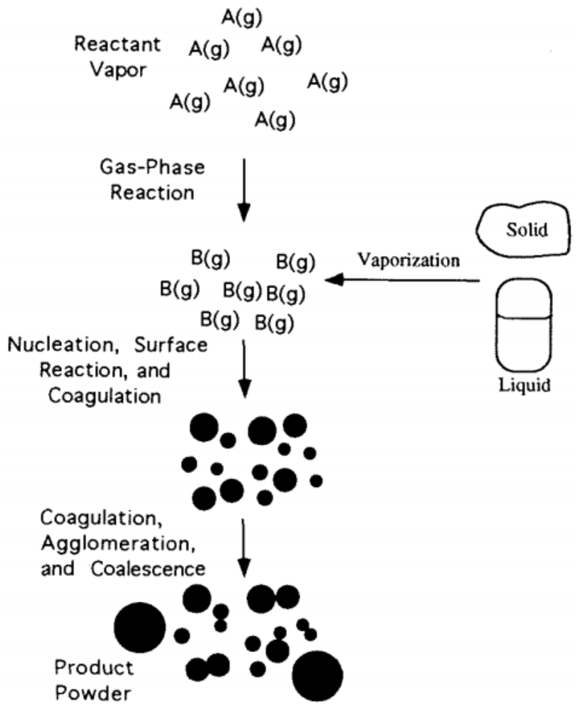

Figure 1.4. Gas phase process. [8]

Droplet formation containing particles

Droplet formation is a method to produce nanoparticle from droplets which are processed with centrifugal forces, pressured air, sound waves, ultrasonic, vibrations and other methods. Droplets are modified to powder through direct pyrolysis or through reactions with other gases. During the pyrolysis the droplet is being sprayed through some hot layer like flame which then accelerates decomposition of flying particles. Formed particles are then collected on filters. Figure 1.5 indicates droplet formation processing.

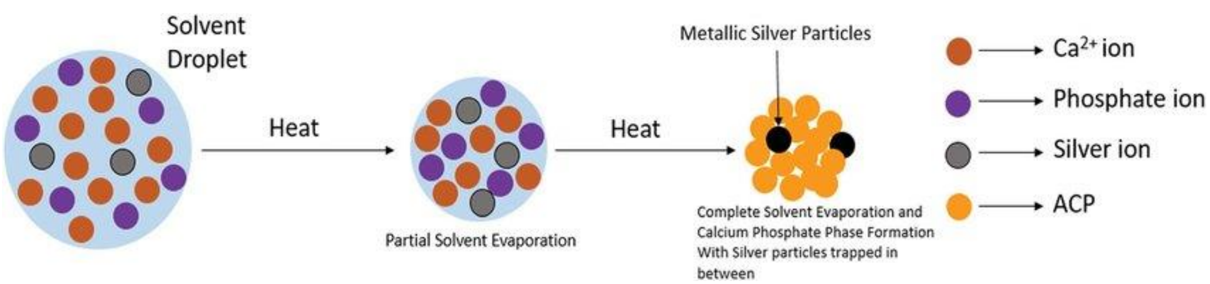

Figure 1.5. Silver nanoparticle manufacturing using droplet formation method. [9]

Liquid phase synthesis

The liquid phase synthesis takes place at lower temperatures than gas-phase synthesis. Most important liquid phase processes to produce nanoparticles are sol-gel and hydrothermal synthesis, seen on Figure 1.3. [7]

Sol-gel synthesis

The synthesis takes place on wet-chemical method to synthesize porous nanoparticles as well as ceramic nanoparticle polymers, metal oxide nanoparticles, and metal nanoparticles. Sol-gel processes can be done in simple conditions and at low temperatures. The term „Sol“ meaning a solid particle dispersion in the size range of 1-100 nm which is divided in water as well as organic solutions. During the sol-gel synthesis processing of materials or precipitation in liquid phase is modified to solid gel through sol-gel conversion. Sol-gel conversion covers three-dimensional cross-linking in nanoparticle solution, where gel contains the main features. Controlled air heat treatment can convert gel to ceramic oxide material. [7]

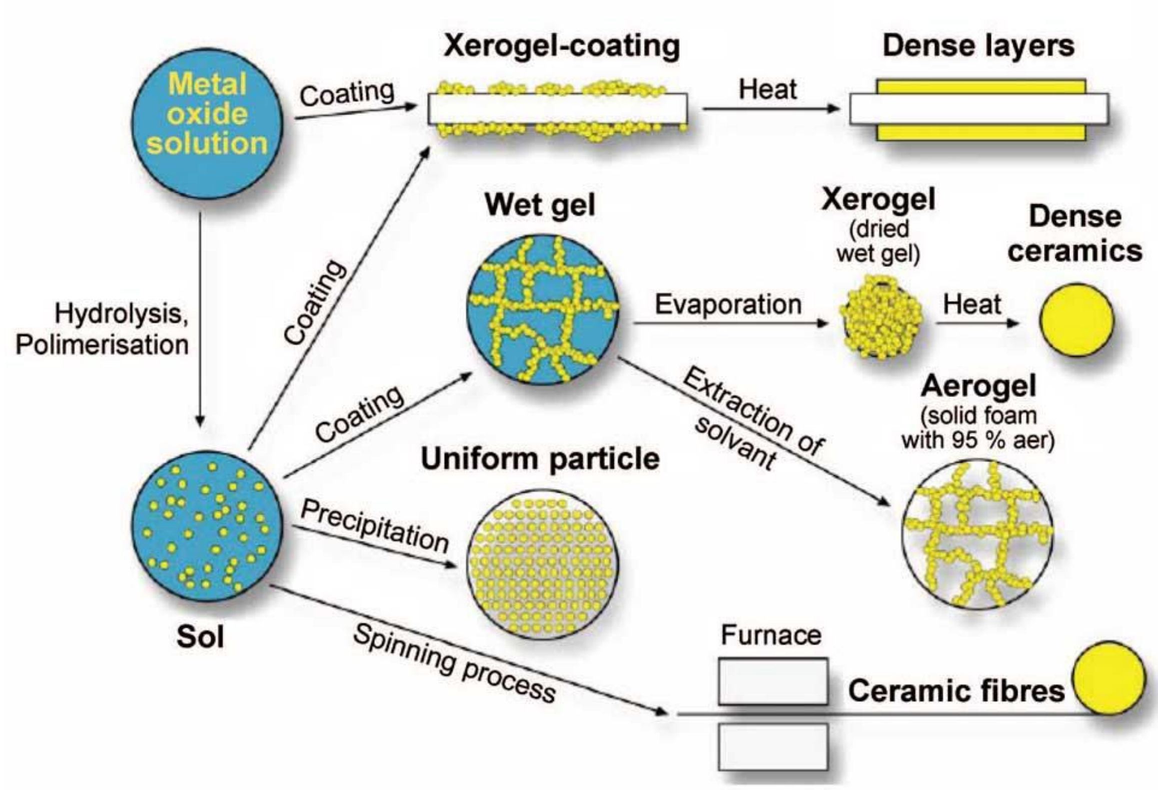

Figure 1.6. Description of sol-gel processes. [7]

Green synthesis

Nanoparticle green synthesis is environmentally friendly, where nanoparticles can be created through treatment of bacteria, fungi and plant extracts. [10]

Using plants in chemical processes is cheap and easy to handle, also their preservation does not need a lot of work. During nanoparticle synthesis, the plant sample is washed with distilled water and then boiled. After boiling, the product is filtered and then rinsed with solvent. Centrifuge enables to separate the nanoparticles from the solvent solution. Producing nanoparticles with green synthesis is environmentally friendly because from this synthesis there is no residual product like gases or toxic chemical by-products. Green synthesis is shown in Figure 1.7. [10]

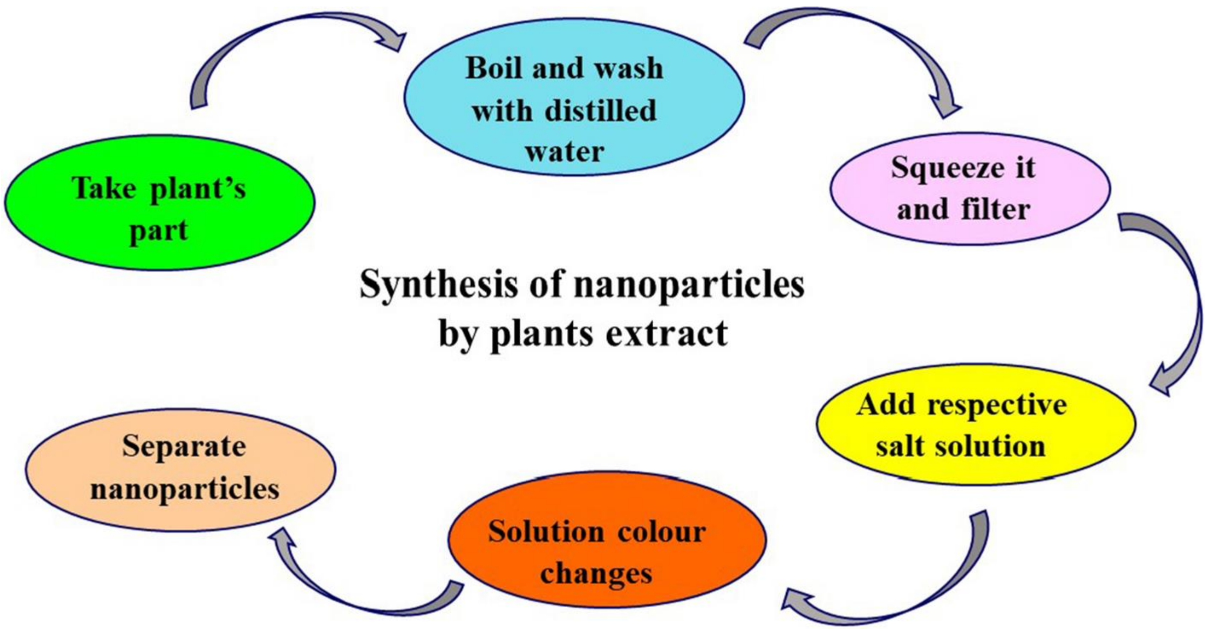

Figure 1.7. Synthesis of nanoparticles by plants extract. [10]

On Figure 1.7 is brought out production of nanoparticles through green synthesis. The plant is washed with distilled water and then it gets boiled. Product is filtered and then added to the salt or metallic solution. The colour of solution changes to the colour of nanoparticles and then may be separated from solution.

2. PREPARING NANOPARTICLES FOR FUEL BLENDING

2.1. Preparation of ZnO nanoparticles

2.1.1. Synthesis with Artemisia

The first patch of ZnO nanoparticles were synthesised with Artemisia plant parts. The end product of the synthesis was brown and sticky powder mass. Nanoparticles are covered with hydrophilic plant extracts that do not dissolve when mixed with diesel fuel to disperse nanoparticles equally in the fuel. Since the powder was sticky and hard to handle, it made it hard to dissolve in the diesel fuel with magnetic stirrer, leaving big fragments inside the diesel. Nanoparticle powder is seen on Figure 2.1.

Figure 2.1. ZnO nanoparticles synthesised from artemisia.

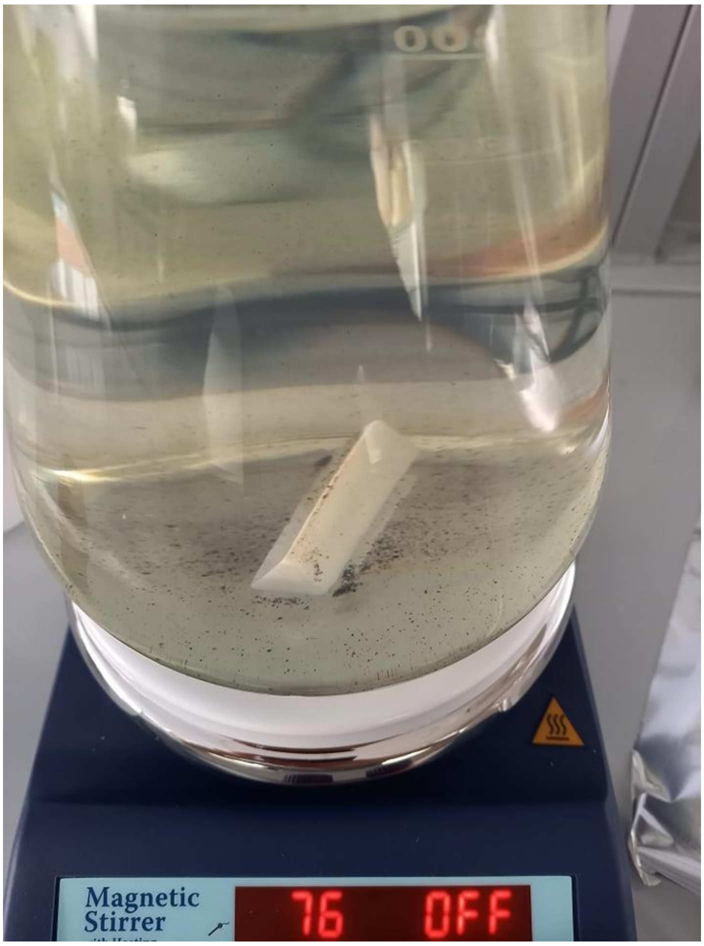

Figure 2.2. ZnO artemisia large particles which did not dissolve.

On figure 2.2 are visible brown residue which did not dissolve after 1.5 hours of stirring on magnetic stirrer at the temperature of 60°C. During this test we found out that diesel fuel loses its features when being heated up. Next tests will be made with diesel fuel at room temperature (25°C). For our combustion engine test, this residue is not ideal because fuel filter will catch it and nanoparticles would not make it to the combustion chamber. In long term, these big particles could also clog the fuel filter. Since this experiment did not satisfy our requirements, we decided to try other plants to get better results.

2.1.2. Synthesis with sunflower seed

Synthesis with sunflower seeds had much better results. ZnO nanoparticles synthesized with sunflower seeds were in yellowish colour, the powder was dryer and did not stick. For mixture we mixed 1L of diesel fuel with 10 mg ZnO nanoparticles to see how the particles dissolve with diesel fuel, see figure 2.3 and figure 2.4.

Figure 2.3. ZnO nanoparticles synthesized with sunflower seeds.

The exact amount of 10 mg of ZnO nanoparticles were measured with high accuracy using a precision balance (Precisa Balance XT120). The main reason we are using green synthesis to synthesize nanoparticles is so we could use plant-based oil to keep nanoparticles floating (colloid) in diesel, otherwise all the nanoparticles would simply fall to the bottom of the fuel tank.

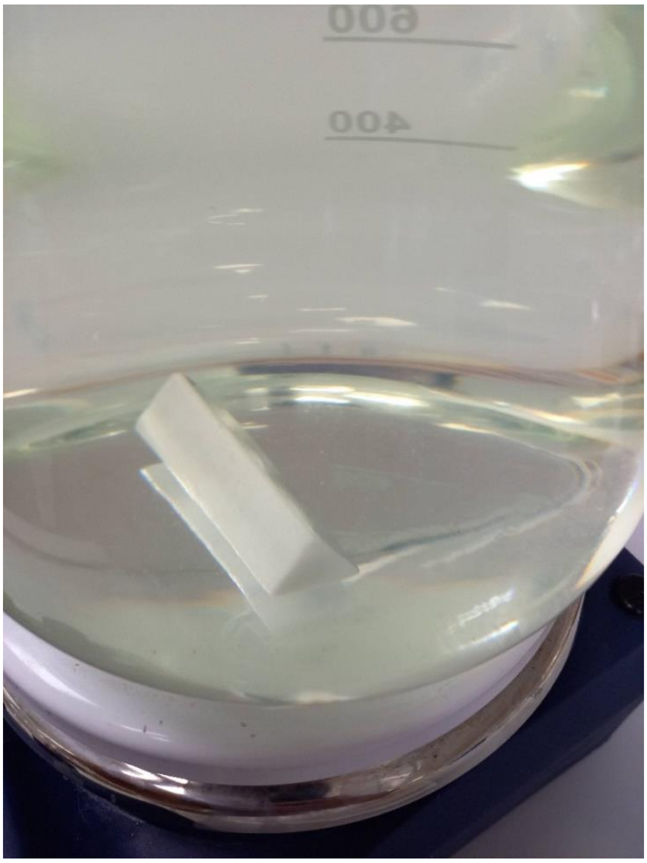

Figure 2.4. ZnO nanoparticles synthesised with sunflower seeds.

After 1.5 hours of stirring on magnetic stirrer the powder was dissolved with very little residue at the bottom (figure 2.4). Fuel temperature was on laboratory temperature while being stirred. Since this test was successful, it is going to be used in determining physical-chemical properties of the fuel followed by combustion test.

2.2. Determining physical-chemical properties of test fuels

During this Master´s thesis, tests were made with winter diesel fuel, which was bought from Alexela gas station in Tartu. Determining physical-chemical features of the fuel without any additives and with diesel fuel with ZnO nanoparticle additives were carried out. Physical-chemical tests were used to obtain differences in fuel colour, distillation character, flash point, kinematic viscosity, cloud point, consistency of water and corrosivity on copperplates.

Visual inspection

Visually inspecting the fuel is an important indicator of showing fuel’s quality. Visual evaluation is made according to ASTM D4176 [6] standard. During the visual evaluation, we monitored diesel fuel colour and content of solid particles, which could clog fuel filter. Diesel fuel used in this Master´s thesis was transparent and had no solid particles.

Measuring density

Diesel fuel density ρ is fuel volume unit mass at the temperature of 15°C. Density unit in SI system is kg/m^3. In laboratory conditions measurements were made with digital *Rudolph Analytical Automatic Density meter*. The measurements were done by following EVS-EN ISO 12185 [7] standard. Measurements are presented in Table 2. Figure 3.1. shows a density measurements device.

Table 2. Diesel fuel density measurement results

Fuel type	Density
Winter diesel fuel	823,7 kg/m^3
Winter diesel fuel with ZnO additives	823,7 kg/m^3

Figure 2.5. *Rudolph Analytical Automatic Density meter* (left). Koehler Instrument K45090 distillation device (right)

Determining distillation characteristics

Diesel fuel fraction structure measurements are made by distillation of 100 ml diesel fuel. Fuel is heated up and cooled down which produced condensation of fuel directly into the recipient cylinder. During this test, we registered fuel's boiling temperature by indicating receiving cylinder and thermometer which was connected to the heatable flask. Boiling temperature is marked by the first diesel fuel droplet falling into the receiving cylinder. Temperatures and condensation volume are being monitored and brought up on table 3. Testing device is presented on figure 3.1.

Table 3. The results of distillation characterisation

Fraction structure indicator	**Temperature or volume percentage**	
	Winter diesel fuel	**Winter diesel fuel with ZnO additives**
Beginning of boiling (IBP)	168	166
10 % volume distillated, °C	192	193
20 % volume distillated, °C	204	202
30 % volume distillated, °C	214	213
40 % volume distillated, °C	224	224
50 % volume distillated, °C	235	234
60 % volume distillated, °C	247	246
70 % volume distillated, °C	258	258
80 % volume distillated, °C	272	271
90 % volume distillated, °C	290	290
95 % volume distillated, °C	307	307

At temperature 180°C distillated volume (%)	5	4
At temperature 250°C distillated volume (%)	63	63
Boiling end temperature, °C	325	324
Distillated, %	98	98,3
Distillation residue, %	2	1,7

Tests were made in laboratory conditions at the normal temperature of 22*°C*, and air pressure of 767 *mm/hg*.

Analyses were made with *Koehler Instrument K45090* distillation device according to standard EN ISO 3405 [11]. On figure 3.1 there are visible receiving cylinder on the left, on the top of the device is flask with diesel fuel to which the thermometer is mounted.

Determining flash point

Flash point is the lowest temperature in which fuel vapours mixed with air are exploding when making contact with the flame. At the point of determining flash point, the diesel fuel is not warm enough to produce enough fuel vapours to ignite fuel. Flash point is characterized as flammability of fuel. According to standard EN ISO 2719 [12] winter diesel fuel flash point is over 55°C. If diesel fuel fails flash point temperature, then that may be caused by high consistency of fraction components or gasoline exposure to the diesel fuel. Testing results of flash point are presented on table 4.

Table 4. The results of testing the flash point

Fuel type	**Flash point, °C**
Winter diesel fuel	62
Winter diesel fuel with ZnO additives	57

The results of the flash point experiment are presented in table 4. Winter diesel fuel has flash point at 62°C and winter diesel fuel with ZnO additives has flash point at 57°C. Both measurements are in the range of standard and difference may be caused by measurement errors.

Determining kinematic viscosity

Kinematic viscosity is fuels flowing characterisation unit. Viscosity is fuels feature to impact particles against opposite movement.

Viscosity tests were made with *CANNON-FENSKE ROUTINE VISCOMETER* capillary viscometer, which has a capillary with a diameter of 0,62 mm and its calibration constant is 0,007870 mm^2/s^2. On figure 3.3 is testing device and its certificate.

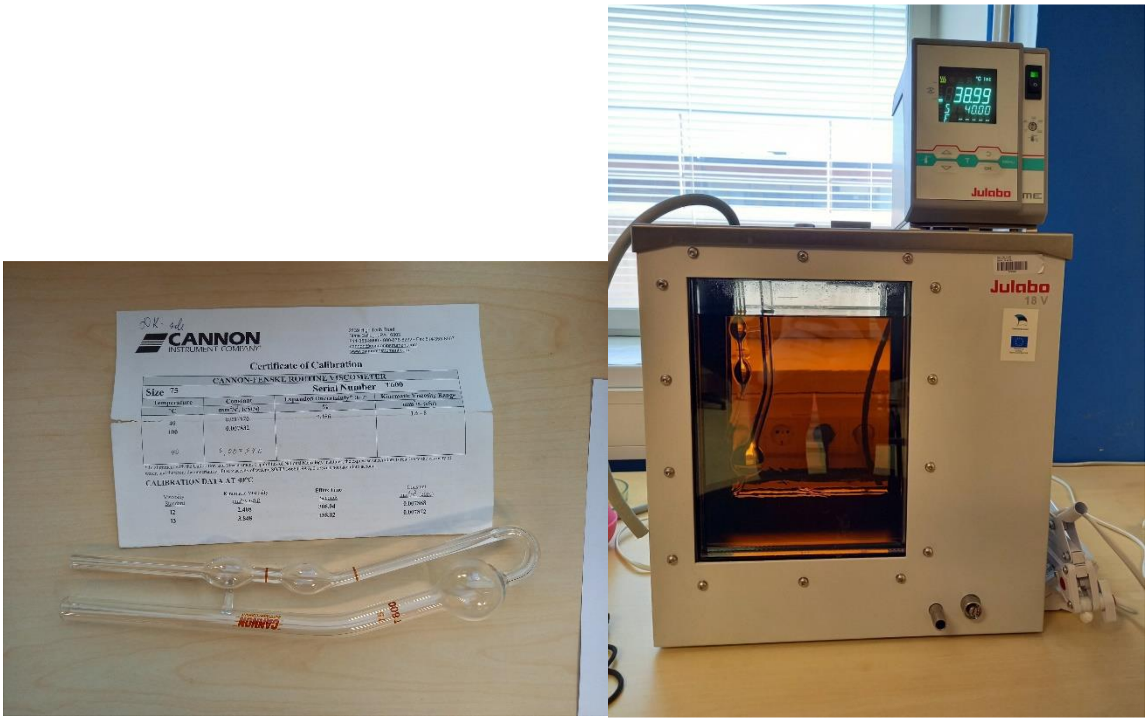

Figure 2.6. *CANNON-FENSKE ROUTINE VISCOMETER* and measuring device with certificate (left). Julabo ME-18V viscometer (right).

During the test of measuring kinematic viscosity, 50 ml of diesel fuel was added to the capillary viscometer. Capillary viscometer was placed into the *Julabo ME-18V* bath to warm up to 40°C. When the bath was at desirable temperature, the measuring process takes place. During the measurement the test liquid was sucked up into the capillary using vacuum pump. Measuring started when fuel was falling through measuring lines on the capillary viscometer. When fuel crossed first line, stopwatch was started and stopped when fuel crossed the end line.

Measurements were repeated 3 times on each fuel type to get an average time. On figure 2.6. is *Julabo ME-18V* viscometer.

Kinematic viscosity is found by multiplying measured time with measuring device constant (formula 2.1):

$$\vartheta = C \cdot t \tag{2.1}$$

Where ϑ is kinematic viscosity, mm^2/s;

C – Viscosimeter calibration constant;

t – Diesel fuel flowing time, *s*.

Obtained results are brought out in table 5.

Table 5. Diesel fuel kinematic viscosity

	Winter diesel fuel	**Winter diesel fuel with ZnO additives**
Diesel fuel viscosity, mm^2/s	1,932	1,920

Winter diesel fuel viscosity is 1,932 mm^2/s. Diesel fuel with ZnO additives viscosity is 1,920 mm^2/s. The difference between test subjects is very small, so it cannot be considered as a valid difference. Measuring kinematic viscosity is made by following EN ISO 3104 [13] standard.

Cloud point

Cloud point is the temperature where paraffins in the fuel are getting crystalized. Cloud point indicates diesel fuel usability with colder temperatures. Summer diesel fuel has much more paraffins and its cloud point is at higher temperatures.

Winter diesel fuel has had fraction particles removed and its frost resistance is better. Measuring cloud point is done by following EVS-EN ISO 3015:2019 [14] standard. Measurement results are brought out in table 7.

Table 7. Diesel fuel cloud point

	Winter diesel fuel	Winter diesel fuel with ZnO additives
Cloud point, °C	-26	-26

Cloud point on Winter diesel fuel is -26°C, diesel fuel with ZnO additives has cloud point at -26°C. Since both fuels have the same cloud point, we can assure that ZnO nanoparticles do not have any bad effects on cloud point.

Water consistency in diesel fuel

Measuring water consistency in diesel fuel is important, because water may corrode the fuel tank, freeze or clog the fuel filter.

For measuring water consistency, we used Mettler Toledo C20 Coulometer titrator (figure 2.7.). Measuring device is based on iodine coulometry, so it could stoichiometrically react with water present in the sample solution.

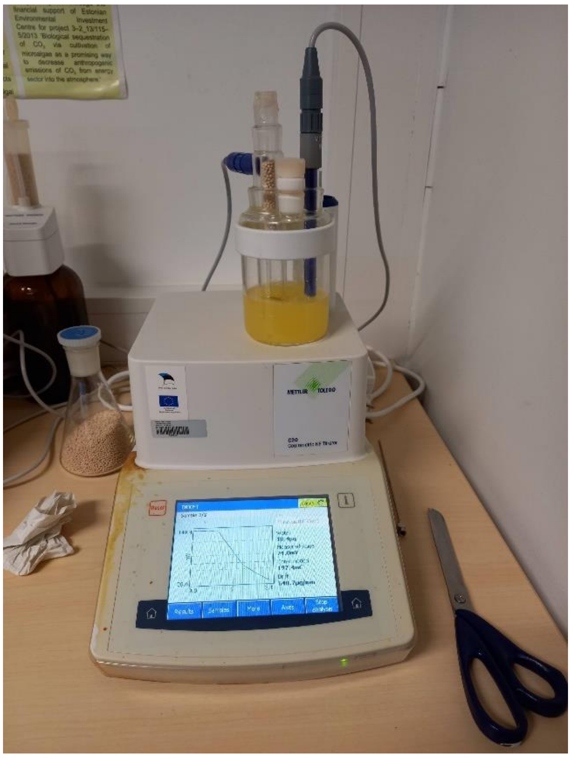

Figure 2.7. Mettler Toledo C20 Coulometric titrator.

Winter diesel fuel water consistency was measured 4 ppm. Winter diesel fuel with ZnO additives had water consistency of 21 ppm. This could have been caused by nanoparticles which were not fully dried or were in the presence of hydrates. 21 ppm of water consistency should not be a problem because the upper limit of water consistency is 200 ppm.

Corrosiveness on copperplate

During the copperplate test, we can identify if diesel fuel contains compounds that could cause corrosion on fuel tank, pumps or other car parts. The fuel corrosion may be caused by active sulfur compounds or if the fuel contains mineral acids or alkaline.

Figure 2.8. ASTM copper strip corrosion standard plate.

Corrosion tests were made by following EN ISO 2160 [15] standard. For each test, cleaned copperplate was used. Winter diesel fuel without additives was in 1a class, which means its corrosion is within normal limits. Corrosiveness test with diesel fuel with ZnO additives had corrosion reading between 1a and 1b.

Determining cetane index

Cetane index is diesel fuel ignition feature characteristic which is gotten from empirical relation. In this test we must know fuel density and temperature at which it distillates over 50%

of its 100 ml [16]. Acquiring cetane index is followed by standard EN ISO 4264 [17]. To find cetane index calculating program was used with formula 2.2:

$$CI = 45{,}2 + 0{,}0892 \cdot T_{10N} + (0{,}131 + 0{,}901 \cdot B) \cdot T_{50N} + (0{,}00523 - 0{,}42 \cdot B) \cdot T_{90N} + 0{,}00049 \cdot (T_{10N^2} - T_{90N^2}) + 107 \cdot B + 60 \cdot B^2 \quad (2.2)$$

$$T_{10N} = T_{10} - 015$$

Where T_{10} is temperature at the distillation volume of 10%, °C.

$$T_{50N} = T_{50} - 060$$

Where T_{50} is temperature at the distillation volume of 50%, °C.

$$T_{90N} = T_{90} - 010$$

Where T_{90} is temperature at the distillation volume of 90%, °C.

$$DN = D - 850$$

Where D is fuel density at 15°C, kg/m^3.

$$B = [exp(-0{,}003 \cdot 5 \cdot DN)] - 0$$

Table 8. Tested fuels cetane index

	Winter diesel fuel	**Winter diesel fuel with ZnO additives**
Cetane index	48,4	48,3

Diesel fuel and ZnO diesel have 0,1 in difference, which is too small to be considered as having an effect on fuel.

Physical-chemical test results can be seen in table 9.

Table 9. Results of fuel physical-chemical properties tests

Properties	Temperature or volume percentage	
	Winter diesel fuel	**Winter diesel fuel with ZnO additives**
Beginning of boiling (IBP)	168	166
10 % volume distillated, °C	192	193
20 % volume distillated, °C	204	202
30 % volume distillated, °C	214	213
40 % volume distillated, °C	224	224
50 % volume distillated, °C	235	234
60 % volume distillated, °C	247	246
70 % volume distillated, °C	258	258
80 % volume distillated, °C	272	271
90 % volume distillated, °C	290	290
95 % volume distillated, °C	307	307
At temperature 180°C distillated volume (%)	5	4
At temperature 250°C distillated volume (%)	63	63
Boiling end temperature, °C	325	324
Distillated, %	98	98,3
Distillation residue, %	2	1,7

Flash point, °C	62	57
Diesel fuel viscosity, mm^2/s	1,932	1,920
Hazing point, °C	-26	-26
Corrosivity on copperplate, ASTM	1a	1b
Cetane index	48,4	48,3

As seen in table 9, there are no major differences between regular diesel fuel and diesel fuel with ZnO additives.

3. ENGINE TESTS

3.1. Testing methodology and test equipment

Engine tests were carried out at the Institute of technology of the Estonian University of Life Sciences. 10 L of regular diesel fuel and diesel fuel containing 10 ppm of ZnO particles were prepared for the tests. During the tests, motor was set to constant speed mode at 2300 rpm and was loaded with 20, 40, 50, 75 and 100% of load. Engine tests were repeated two times to maximize precision and reproducibility.

Engine tests were carried out with AVL 5402 CR DI Single cylinder engine. Engine specification is presented in table 10. Engine is connected to the Schenck Dynas3 LI250 engine test stand, that allows the engine to operate on different loads.

Table 10. Engine test equipment

Detail		**Measurement**
AVL 5402 CR DI engine	Bore, mm	85
	Stroke, mm	90
	Displacement, ccm	510
	Maximum speed, rpm	4200
	Maximum firing pressure, bar	170
	BMEP, bar	14, at 2300 rpm
	Maximum output power, kW	19, at 4200 rpm
	Compression ratio	17:1
Fuel supply system		Commonrail
Control hardware		AVL RPEMS
Software		INCA 7.1
Fuel consumption		AVL 7351
Combustion pressure		AVL Indimodul 621
AIR consumption		AVL Flowsonix Air 100

Main goal during this thesis is to determine whether the addition of 10 ppm of ZnO nanoparticles affect diesel fuels combustion parameters or not. During the tests, exhaust gases, torque output at different loads, fuel consumption and combustion pressure were measured.

Engine tests were made with regular diesel fuel and diesel fuel containing 10 ppm of ZnO nanoparticle. The tests with regular diesel fuel were done first. At the beginning of the test few litres of fuel mixture were flushed through system to flush out any old fuel residue to maximise reliability. These steps were done with both fuels.

Bosch BEA 350 is an exhaust gas and diagnostics device. The device is equipped with integrated on-board diagnostics, exhaust gas sensors. It is suitable for all the cars and engines. Bosch BEA 350 is easily movable because it is placed on a trolley. More specifications are seen on figure 3.1.

Designation	Measuring range	Resolution
Exhaust measurement module		
CO	0 – 10 % vol.	0.001 % vol
CO_2	0 – 18 % vol	0.01 % vol
HC	0 – 9999 ppm	1.0 ppm
O_2	0 – 22 % vol	0.01 % vol
NO	0 – 5000 ppm	1.0 ppm
Lambda	0.5 – 1.8	0.001
CO_{vrai}	0 – 10 %	0.01 %
Accuracy according to OIML class 0		

Figure 3.1. Bosch BEA 350 exhaust gas analyser specifications [18]

In order to get more test fuel numeric data we compared relative air fuel ratio, engine power, efficiency and specific fuel consumption. Calculations were carried out with calculating program. Formulas used in the measurement result analysis are presented as followed: [19]

Relative air fuel ratio:

$$\lambda_a = \frac{B_a}{(14{,}3 \cdot B_f)} \tag{3.1}$$

Where B_a is air mass flow, kg/h;

B_f - fuel consumption, kg/h.

Engine power:

$$P_e = \frac{T_e \cdot n_e}{9550}, kW \quad (3.2)$$

Where T_e is engine torque, Nm;

n_e - crankshaft rotational speed, min^{-1}.

Efficiency:

$$\eta_e = \frac{3600}{(Q_a \cdot b)} \quad (3.3)$$

Where Q_a is dieselfuel lower heating value, MJ/kg;

b_e - specific fuel consumption, g/kWh.

Specific fuel consumption:

$$b_e = \frac{1000 \cdot B_f}{P_e}, g \cdot (kW \cdot h)^{-1} \quad (3.4)$$

Friction power:

$$P_{mk} = \frac{p_{mk} \cdot i \cdot V_h \cdot n_e}{30 \cdot \tau_t}, kW \quad (3.5)$$

Where i is number of cylinders.

Indicator pressure:

$$p_i = p_e + p_{mk}, MPa \quad (3.6)$$

Indicator power:

$$P_i = P_e + P_{mk}, kW \tag{3.7}$$

Efficiency:

$$\eta_e = \frac{P_e}{P_e + P_{mk}} \tag{3.8}$$

Indicator specific fuel consumption:

$$b_i = \frac{1000 \cdot B_f}{P_i}, g \cdot (kW \cdot h)^{-1} \tag{3.9}$$

3.2. Test result analysis

Exhaust gas analysis

During this thesis, our main goal was to study how 10 ppm of ZnO nanoparticles can affect exhaust gases, fuel consumption, burning pressure and torque in diesel fuel engine. The exhaust gases analyses are summarized in table 11 and table 12.

Table 11. Diesel fuel exhaust gas test results

Date	**26.03.21**	**Diesel fuel**									
Exhaust gas test results measured according to ISO 8178-1											
Load	%	20	20	40	40	50	50	75	75	100	100
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
α	%	17,6	0	26,1	0	29,9	0	47,3	0	100	0
n_e	rpm	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300

t_{env}	°C	21	21	21	21	21	21	21	21	21	21
φ_{env}	%	26	24	26	24	26	24	26	24	26	24
t_e	°C	90	90	90	90	90	90	90	90	90	90
t_{oil}	°C	90	90	90	90	90	90	90	90	90	90
p_{oil}	bar	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3
B_a	kg/h	34,64	34,34	35,10	34,98	35,35	35,17	34,94	34,39	33,90	34
t_{egt}	°C	260	260	359	356	410	410	529	540	600	600
Exhaust gas											
Load	%	20	20	40	40	50	50	75	75	100	100
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
λ		4,397	4,269	3,071	3,591	2,783	2,798	2,385	2,353	1,594	1,611
CO	%	0,034	0,037	0,025	0,028	0,028	0,031	0,107	0,106	2,922	2,821
CO_2	%	3,325	3,412	4,801	4,840	5,307	5,265	6,130	6,180	6,111	6,01
HC	Ppm	1,166	5,2	1,833	4,75	1	7	0,833	9	38,66	56,66
O_2	%	13,93	0	12,21	0	10,846	0	10,59	0	8,264	0
NO	ppm	88,28	112	111,1	148,5	107,2	151,2	122,4	167,4	107,1	145,8
Soot	ppm	0,02	0,005	0,079	0,09	0,203	0,182	0,910	1,054	9,99	9,674

Table 12. Dieselfuel + ZnO exhaust gas test results

Date	**26.03.21**	**Dieselfuel + ZnO**									
Exhaust gas test results measured according to ISO 8178-1											
Load	%	20	20	40	40	50	50	75	75	100	100
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
α	%	17,6	17,6	26,1	26,1	29,9	29,9	47,3	47,3	100	100
n_e	rpm	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300
t_{env}	°C	21	20	21	20	21	20	21	20	21	20
φ_{env}	%	26	24	26	24	26	24	26	24	26	24
t_e	°C	90	90	90	90	90	90	90	90	90	90
t_{oil}	°C	90	90	90	90	90	90	90	90	90	90
p_{oil}	bar	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3
B_a	kg/h	34,65	34,55	34,80	34,86	35,25	34,69	35,33	34,53	33,68	33,90
t_{egt}	°C	256	258	358	355	382	409	522	530	603	588
Exhaust gas											
Load	%	20	20	40	40	50	50	75	75	100	100
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
λ		4,669	4,350	0	3,100	2,783	2,848	2,306	2,323	1,748	1,583
CO	%	0,036	0,038	0	0,021	0,059	0,030	0,107	0,182	2,660	2,909
CO_2	%	3,125	3,352	0	4,760	5,280	5,187	6,333	6,21	5,566	6,273
HC	Ppm	2	3	0	2,750	32,5	3	2	5	39	38
O_2	%	14,17	16,21	0	14,30	10,93	13,74	10,32	12,18	9,08	9,602
NO	ppm	86,71	110,5	0	141,5	104,8	149,0	135,3	158,0	95,28	136,0
Soot	ppm	0	0	0	0,072	0,163	0,140	0,708	0,935	9,99	9,954

Data from Table 11 and Table 12 are represented on Figure 3.2 to Figure 3.8. Lambda is an indicator that represents the measure of air and fuel mixture in the exhaust gases. As seen on Figure 3.2. all of the results are similar and stay in the same range.

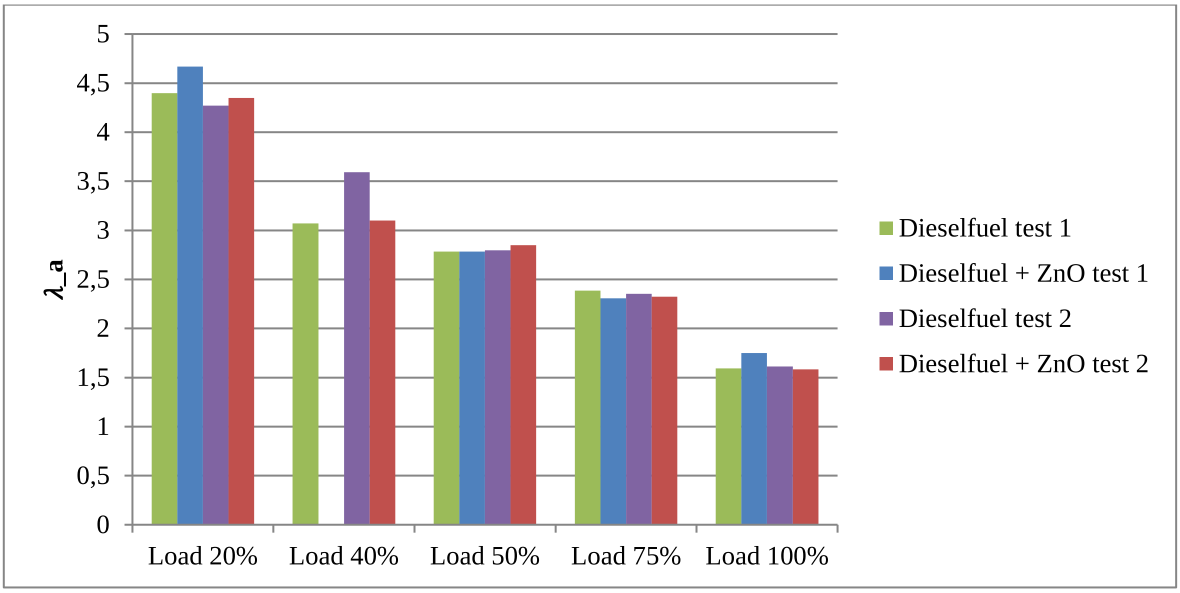

Figure 3.2. Diesel fuel and Diesel fuel with ZnO additives lambda comparison on different loads.

As seen on Figure 3.3, ZnO nanoparticles have slightly lower percentage during first test on 100% load. During second test diesel fuel and diesel fuel with ZnO additives have quite similar results, which shows that 10 ppm of ZnO nanoparticles does not affect CO in the exhaust fumes.

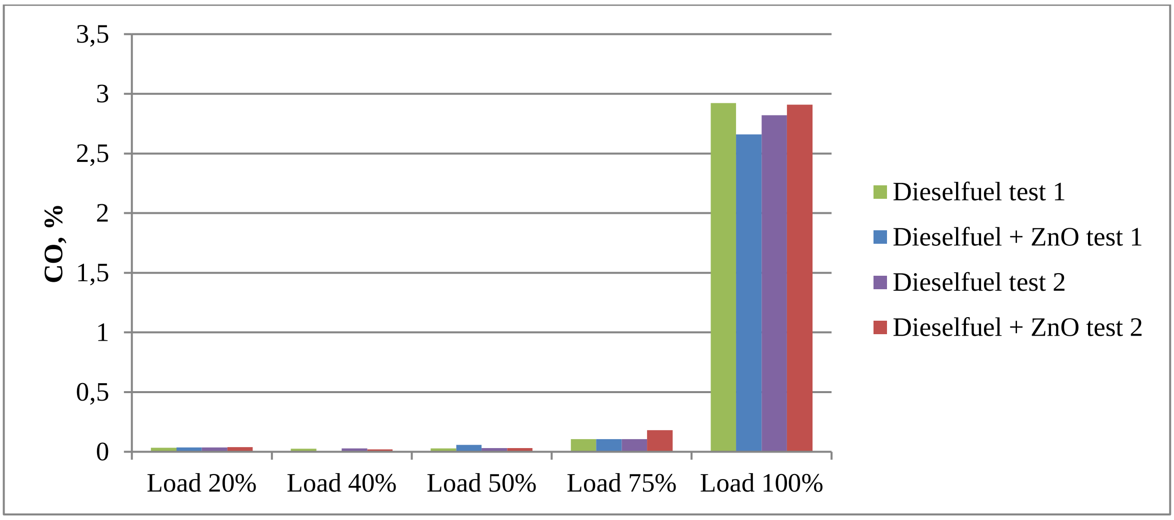

Figure 3.3. CO comparison between diesel fuel and diesel fuel with ZnO additives on different loads.

CO_2 values are in similar range; values are visualized on Figure 3.4.

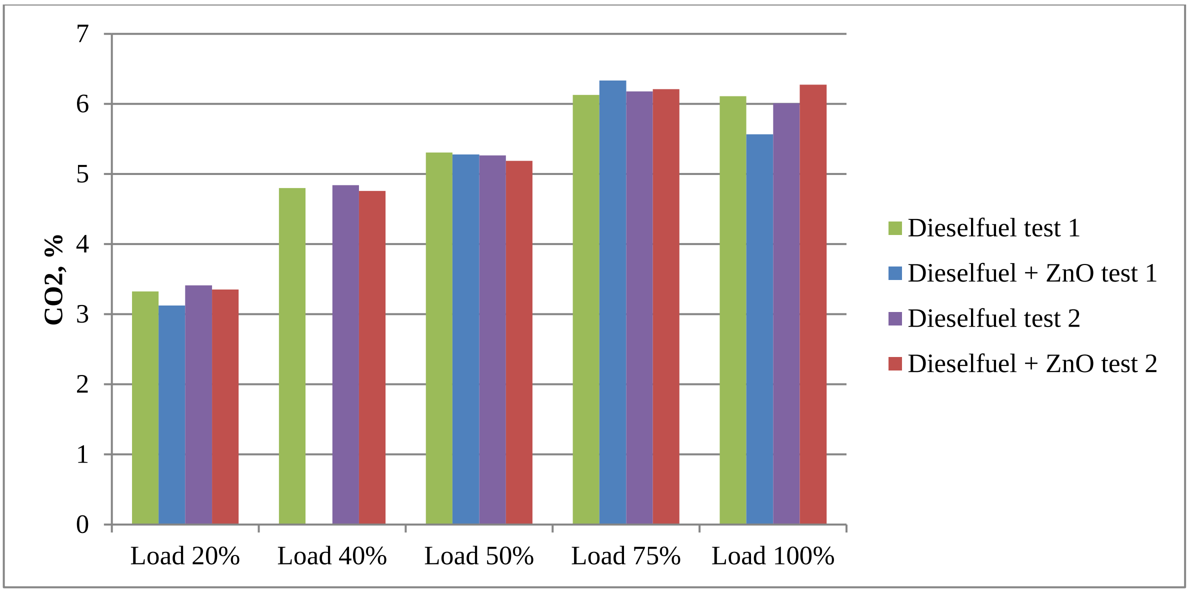

Figure 3.4. CO_2 comparison on different loads with two tests on both fuels.

On Figure 3.5, the results of HC measurements in the exhaust gases are provided. Under a load of 50 % Diesel fuel with ZnO additives are marginally higher, which is in the range of the measuring error. Same principle applies to diesel fuel test 2 result at the load of 100%.

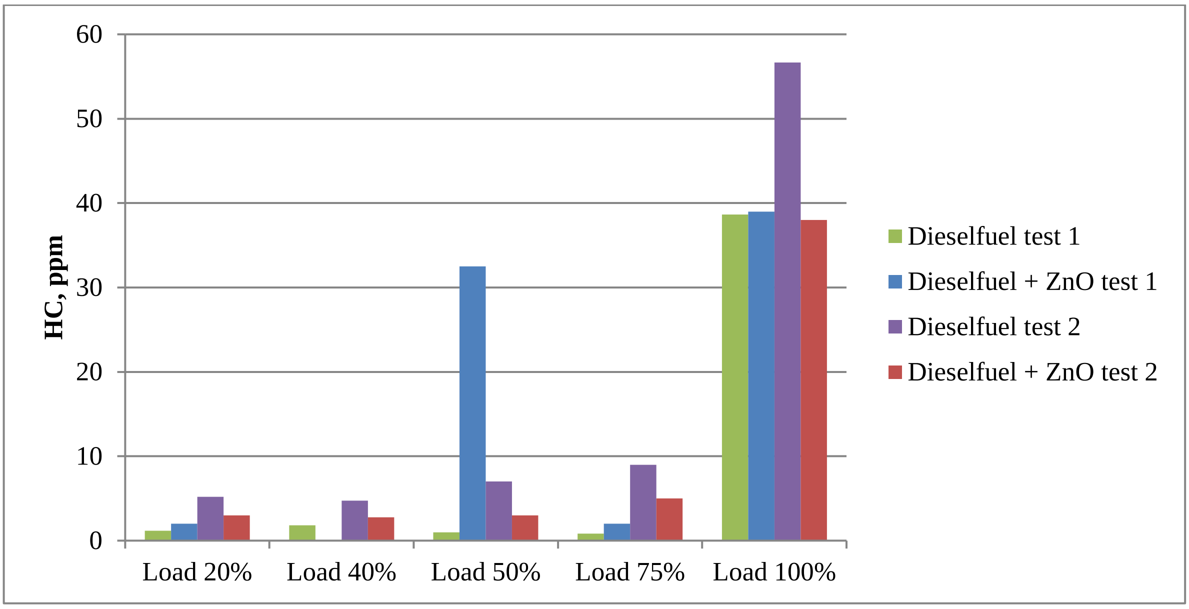

Figure 3.5. Diesel fuel and diesel fuel with ZnO additives HC comparison on different loads.

The main interest was on the impact that 10 ppm of ZnO nanoparticles can have on NO_x release during the fuel combustion. The results are reported on Figure 3.6 and it can be seen that diesel fuel that contains 10 ppm of ZnO nanoparticles release a lower amount of NOx gas. Diesel fuel with ZnO additives also have slightly lower values than normal diesel fuel during test 2.

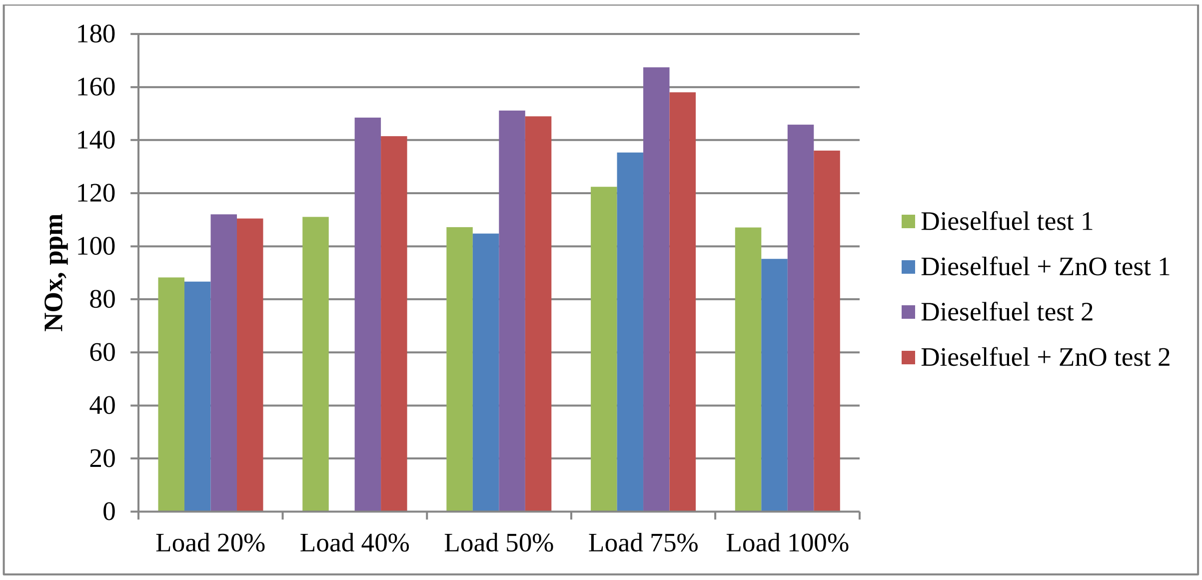

Figure 3.6. Diesel fuel and diesel fuel with ZnO additives NO_x comparison

ZnO nanoparticles do not have any impact on soot emissions as seen on Figure 3.7.

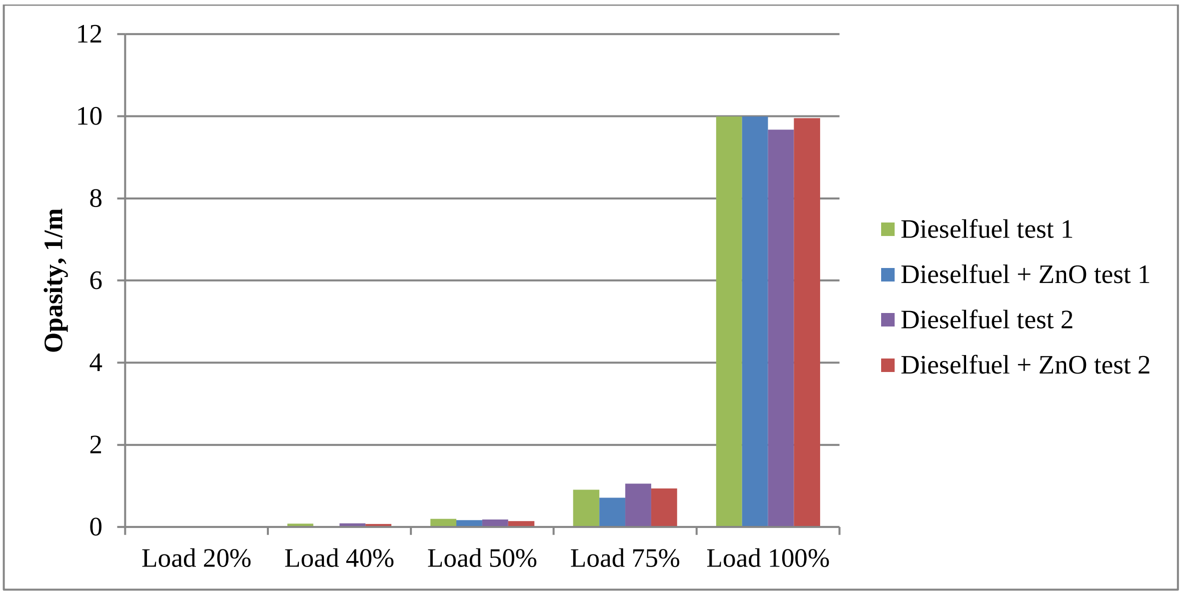

Figure 3.7. Soot comparison on different loads on two test with both fuels.

Calculated relative air fuel ratio

Relative air fuel ratio is an indicator that shows air and fuel ratios theoretical and actual usage during fuel burning [20]. Relative air fuel ratio is calculated using computer program and formula 3.1.

Table 13. Calculated relative air fuel ratio during diesel fuel test

Date	**01.05.21**	**Diesel fuel**									
Calculated relative air fuel ratio											
Load	%	20	20	40	40	50	50	75	75	100	100
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
λ_a		4,249	3,829	2,854	2,653	2,447	2,362	1,745	1,643	0,944	0,941

Table 14. Calculated relative air fuel ratio during diesel fuel + ZnO test

Date	**01.05.21**	**Diesel fuel + Zno**									
Calculated relative air fuel ratio											
Load	%	20	20	40	40	50	50	75	75	100	100
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
λ_a		4,405	4,045	2,765	2,763	2,465	2,366	1,739	1,682	0,916	0,953

As seen in Table 13 and Table 14 there are no big differences in relative air fuel ratio. Excess air fuel ratio is visualized on Figure 3.8.

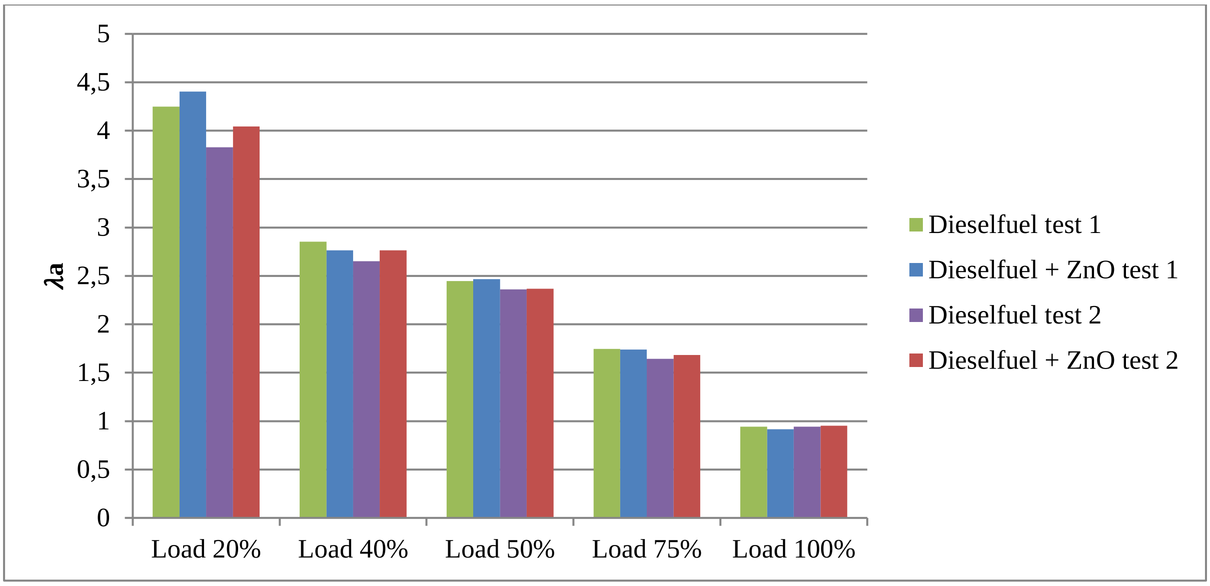

Figure 3.8. Excess air factor during the engine tests at different loads.

Torque analysis

Torque tests with current fuels were done with different levels of load to see how such fuels perform. The tests were carried out at the loads of 20, 40, 50, 75 and 100%. Results of the torque tests are seen in Table 15 and on Figure 3.9.

Table 15. Torque results at different loads

Diesel fuel	Diesel fuel		Diesel fuel + ZnO	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	4,640	4,750	3,520	4,210
LOAD 40%	11,14	11,12	10,81	10,64
LOAD 50%	13,64	13,29	12,74	12,94
LOAD 75%	20,33	20,57	20,05	19,83
LOAD 100%	29,20	28,70	28,78	27,68

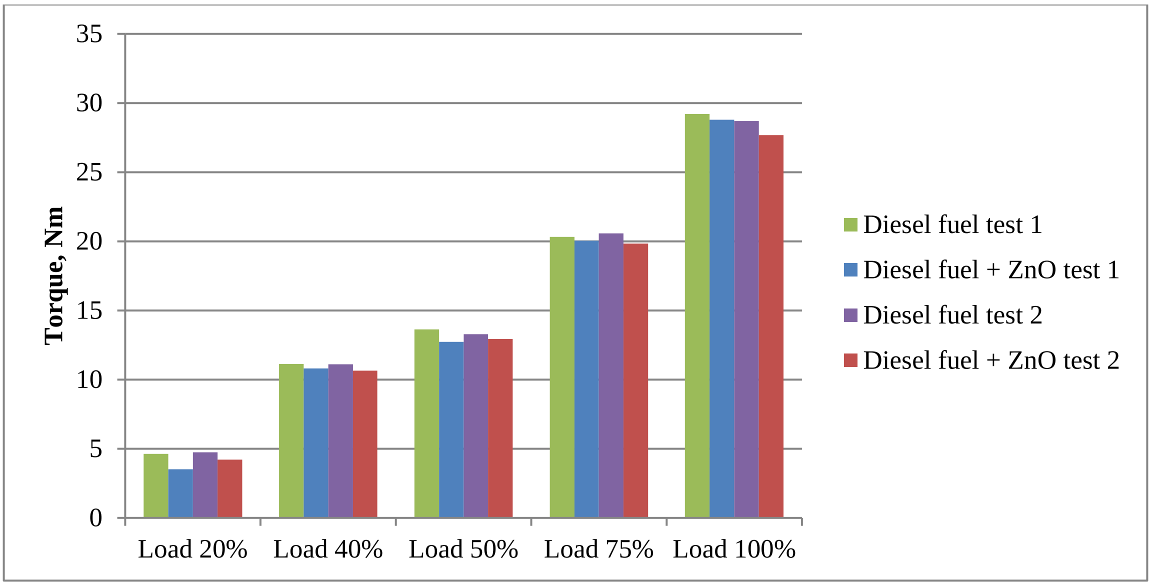

Figure 3.9. Torque test results.

As seen from Table 15 and Figure 3.9, the difference between diesel fuel and diesel fuel + ZnO does not have that much of a difference. The engine tests do not highlight any improvements with the addition of 10 ppm of ZnO nanoparticles.

Fuel consumption

During the engine test fuel consumption was measured with AVL 7351. To get precise results AVL 7351 was set to measure instantaneous value, density and fuels temperature. Results can be seen in Table 16 and 17 and on Figure 3.10

Table 16. Diesel fuel consumption

Diesel fuel	**Instantaneous value, kg/h**		**Density, kg/m^3**		**Temperature, °C**	
	Test 1.	Test 2.	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	0,574	0,627	818,0	827,2	23,79	24,21
LOAD 40%	0,861	0,860	818,0	827,1	23,77	24,32
LOAD 50%	1,010	1,010	818,1	827,2	23,73	24,16

LOAD 75%	1,398	1,463	818,2	827,2	23,69	24,07
LOAD 100%	2,510	2,526 2,51	1 818,2	827,1	23,53	24,01

Table 17. Diesel fuel + ZnO fuel consumption

Diesel fuel + ZnO	Instantaneous value, kg/h		Density, kg/m^3		Temperature, °C	
	Test 1.	Test 2.	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	0,554	0,597	817,1	828,3	24,69	23,16
LOAD 40%	0,883	0,880	817,1	828,4	24,71	23,11
LOAD 50%	0,998	1,025	817,0	828,5	24,79	23,04
LOAD 75%	1,419	1,435	817,0	828,5	24,90	22,97
LOAD 100%	2,566	2,487	816.8	828,5	25,03	22,83

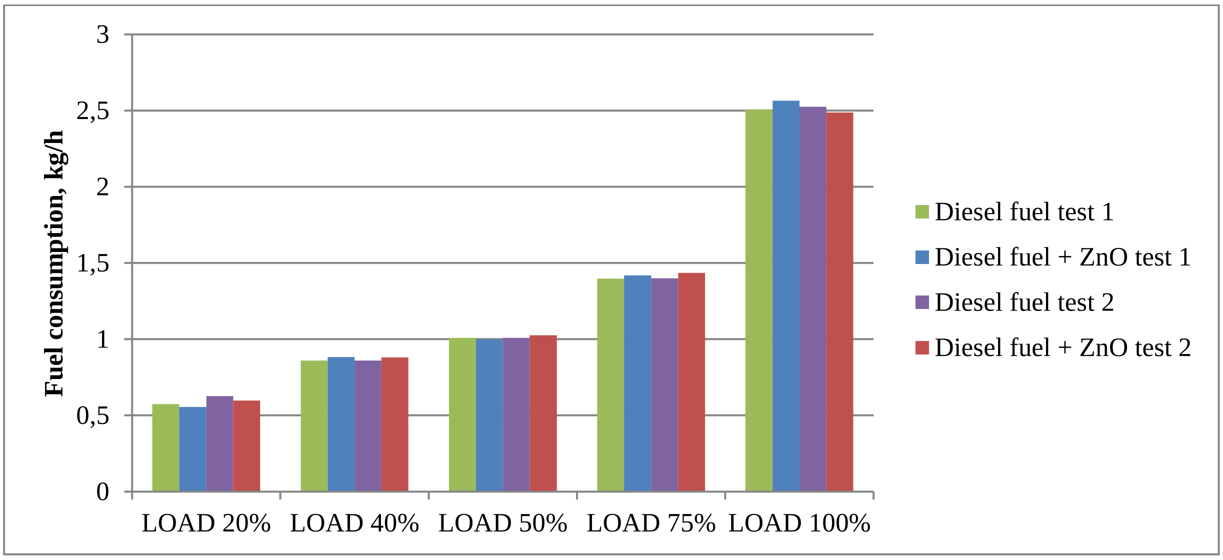

Figure 3.10. Fuel consumption during engine test.

Fuel consumption seems to be a little higher with ZnO additives than regular diesel fuel. Higher values can be seen at loads 40, 50 and 75% as well as diesel fuel with ZnO additives on test 1, at 100% load.

Engine efficiency

Engine efficiency is an indicator that shows how much of the energy produced by the engine can actually be converted into useful energy. Efficiency can be measured by comparing input energy in the fuel and output energy at the crankshaft or flywheel. Energy is lost as heat during the running of the energy that is not recovered. Engine efficiency can be calculated with formula 3.3. Calculated data of engine efficiency is seen in Table 18.

Table 18. Engine efficiency

	Diesel fuel, %		**Diesel fuel + ZnO, %**	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	16,27	11,31	17,26	14,19
LOAD 40%	26,09	23,64	17,61	24,32
LOAD 50%	27,22	24,67	26,82	25,45
LOAD 75%	29,31	27,63	29,21	27,86
LOAD 100%	23,46	22,97	23,33	22,43

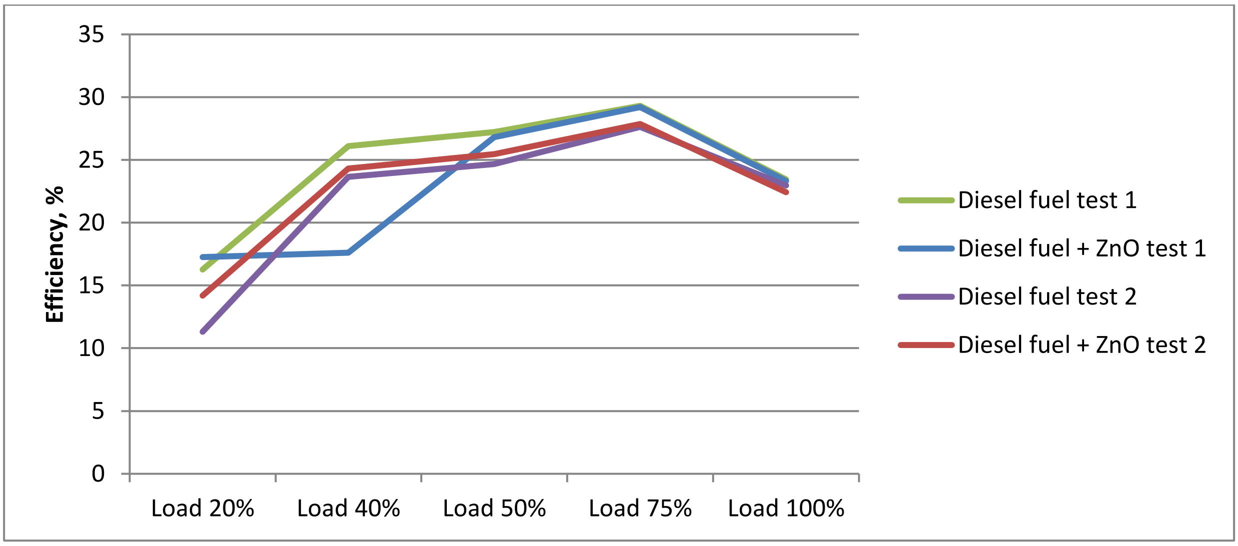

Figure 3.11. Engine efficiency.

As seen on Figure 3.11, tested diesel fuels do not have big differences in efficiency. Diesel fuel with ZnO additives stands out at 40% load because it has lower value, otherwise, all the tests have similar trend line. Calculated mechanical power loss, mechanical efficiency, average indicator pressure, indicator power and fuel indicator specific consumption are visible on appendix A.

Power

The engine power indicates power which is available at the output shaft which is connected to the flywheel. This kind of power is the available power developed by the engine. Power can be calculated with formula 3.2. Power is visualized on Figure 3.12. Calculated data is in Table 19.

Table 19. Power

	Diesel fuel, kW		**Diesel fuel + ZnO, kW**	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	1,117	0,847	0,847	1,013
LOAD 40%	2,683	2,603	2,678	2,562
LOAD 50%	3,285	3,068	3,200	3,116
LOAD 75%	4,896	4,828	4,954	4,775
LOAD 100%	7,032	6,931	6,912	6,666

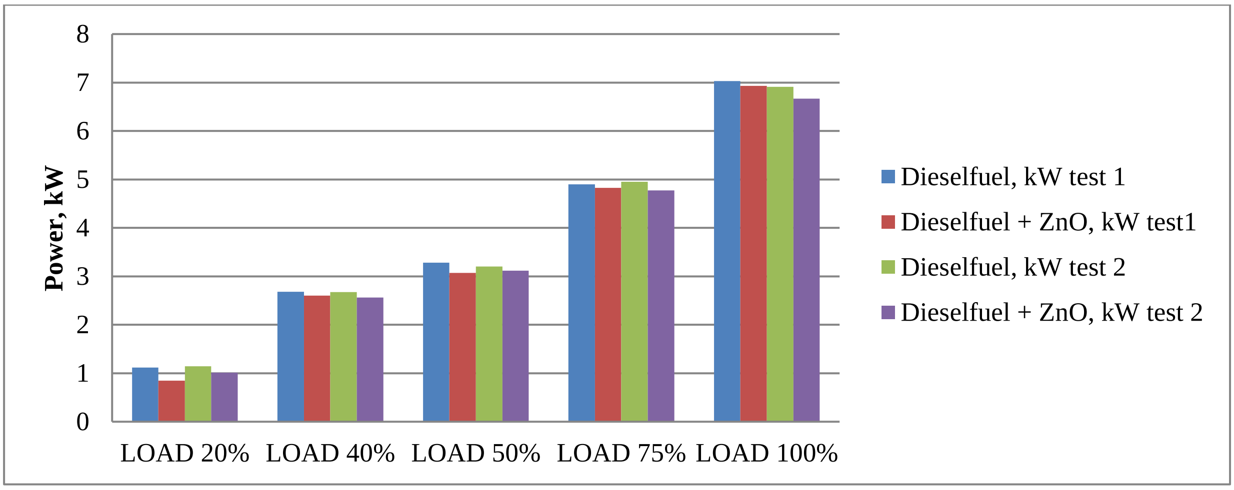

Figure 3.12. Power developed during engine tests.

Diesel fuel with ZnO additives have slightly lower test results, biggest difference is at 100% load, where difference is 0,252 kW.

Specific fuel consumption

Specific fuel consumption is the effectiveness of fuel which is represented with a unit of g/kWh. The specific fuel consumption is found using formula 3.5. Calculations are done with calculating program and are brought out in Table 20 and on Figure 3.13.

Table 20. Specific fuel consumption.

	Diesel fuel, g/kWh		Diesel fuel + ZnO, g/kWh	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	514,3	548,3	654,2	589,7
LOAD 40%	320,8	344,2	339,4	344,2
LOAD 50%	307,5	325,2	325,5	328,9
LOAD 75%	285,6	295,3	293,9	300,5
LOAD 100%	356,8	365,4	370,2	373,2

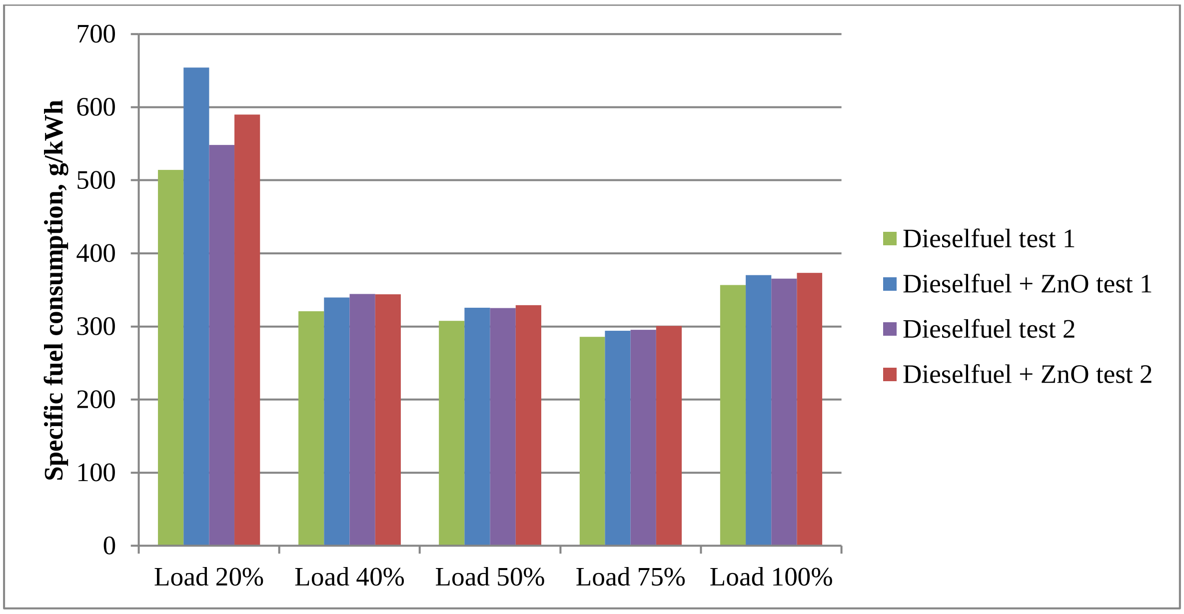

Figure 3.13. Specific fuel consumption.

Specific fuel consumption values are mainly the same except value with ZnO additive at 20% load. That may be caused by measuring inaccuracy.

Engine combustion pressure analysis

Pressure-volume diagram is a measure that takes place inside the cylinder. Pressure-volume diagram is drawn by plotting its value against the angle of the crankshaft during a complete engine cycle, which is 720 degrees. [21]

The combustion pressure characteristic indicates cylinder pressure relation to the angle of the crankshaft. At the rotational speed of 2300 rpm the differences are minimal. Load characteristics are on Figures 3.14 to Figure 3.18. Current measurements are done with diesel fuel test 1 and diesel fuel + ZnO test 1.

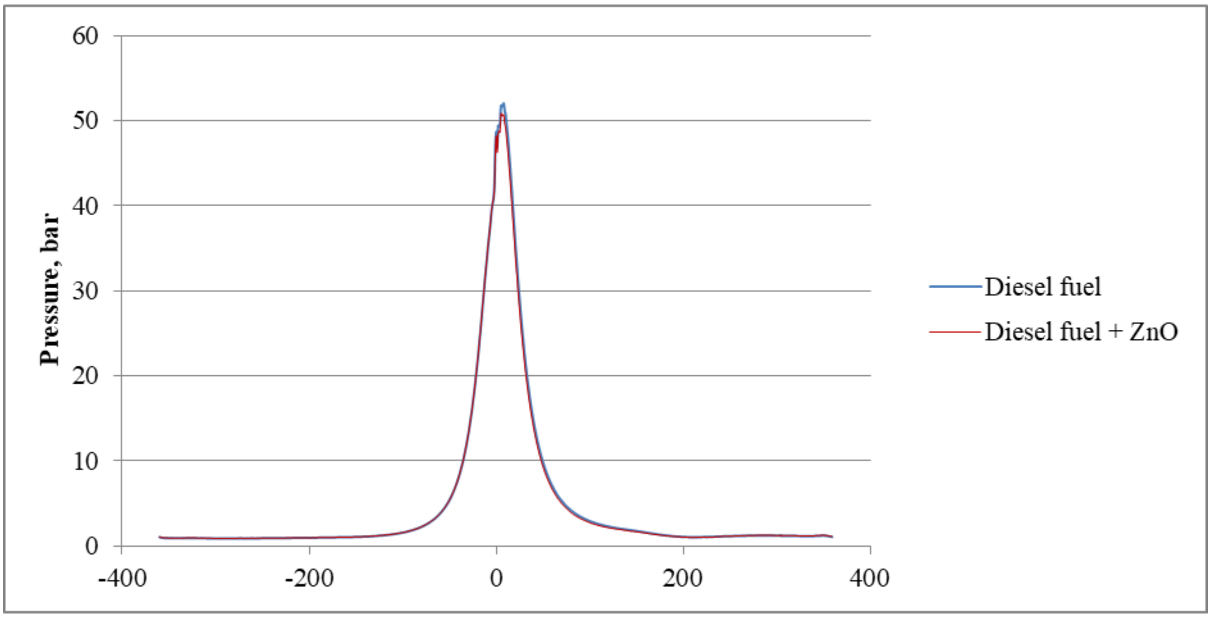

Figure 3.14. Combustion pressure at the load of 20%.

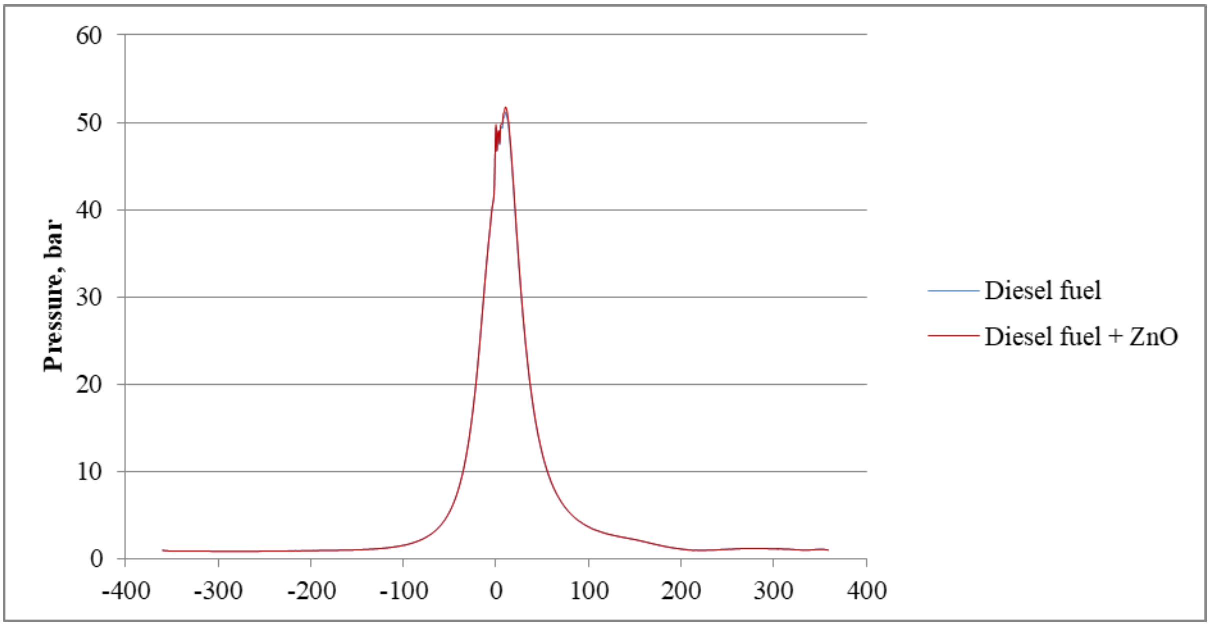

Figure 3.15. Combustion pressure at the load of 40%.

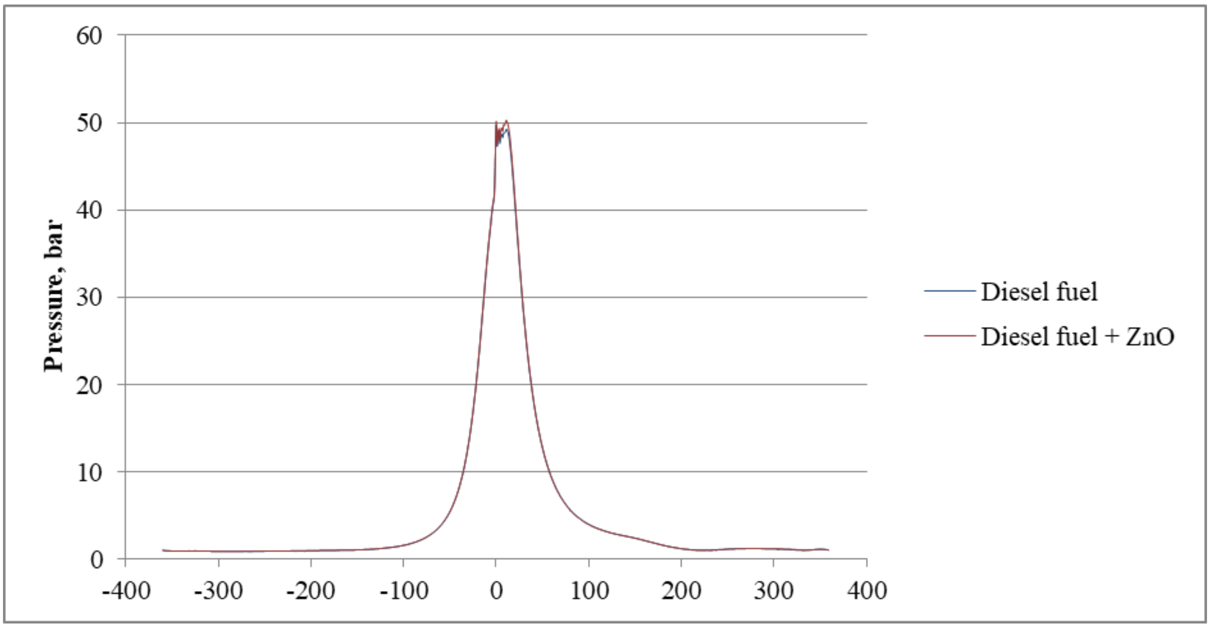

Figure 3.16. Combustion pressure at the load of 50%.

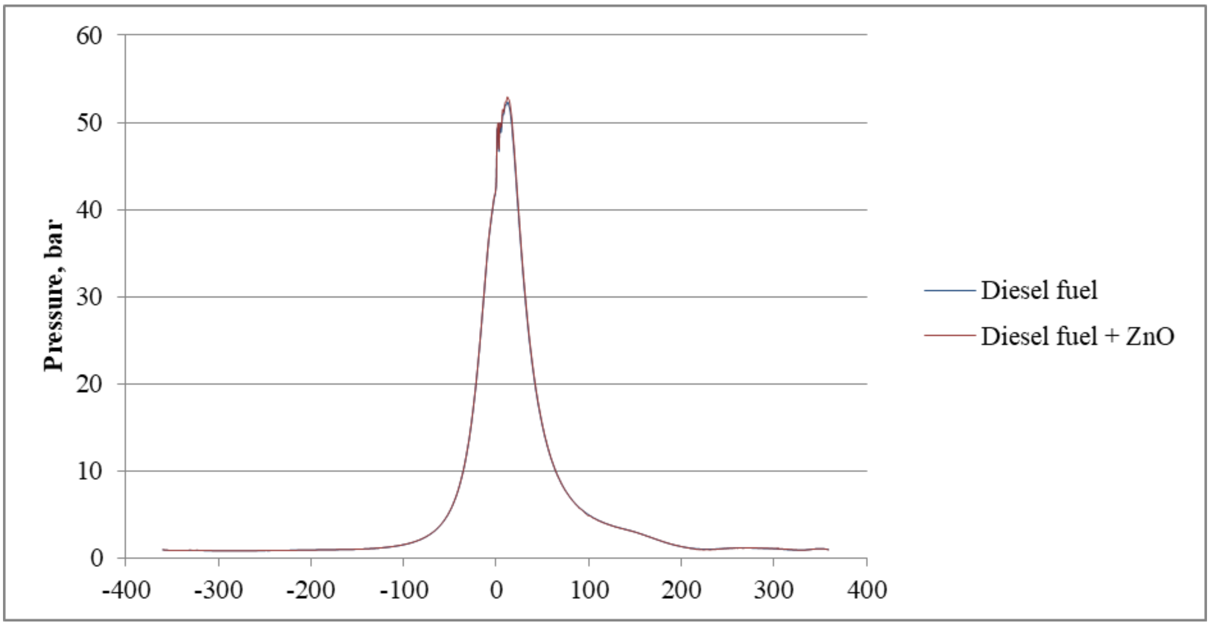

Figure 3.17. Combustion pressure at the load of 75%.

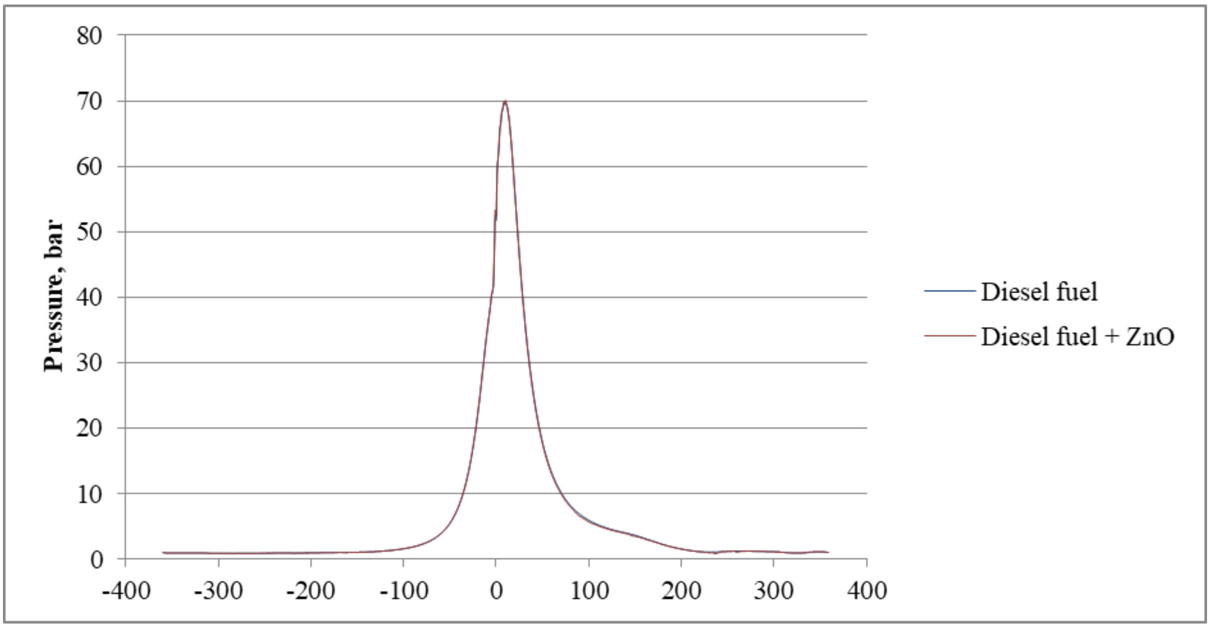

Figure 3.18. Combustion pressure at the load of 100%.

As seen from Figures 3.12 to 3.16 there are no differences in the crank shaft angles at various loads. All of the measurements are in very similar values and cannot be differentiated on the figures.

SUMMARY AND CONCLUSION

The main objective of this master´s thesis was to study the effect that nanoparticles have on diesel fuel. According to literature results, we decided to proceed with testing using Zinc oxide nanoparticles that were synthesized by green synthesis method. We decided to use green synthesis because it is more environmentally friendly than other methods. This brought out a problem with choosing the most suitable plant for the synthesis of ZnO nanoparticles as a nano-additive in fuel. For this reason, an oil rich plant part such as sunflower seeds, were selected to promote a homogeneous dispersion of ZnO nanoparticles in the diesel fuel to form a colloidal solution.

Literature was reviewed to define the state of the art on this topic. There are reports on several tests with diesel fuel and nanoparticle additives which show positive results. The problem of the published works lies in the large quantity of nanoparticles they add, which is not financially and environmentally reasonable.

During the preparing of the nanoparticles we discovered that sunflower seeds are suitable for the synthesis of ZnO nanoparticles aimed for such application. The product is yellowish in colour; texture is fairly dry and dissolves easily in diesel fuel. We also tried to synthesize with Artemisia, but the result was very sticky nanoparticles that were difficult to disperse in diesel fuel and big agglomerate of nanoparticles were visible at the bottom of the bottle containing the diesel fuel.

To get the most precise results, we performed physical and chemical tests on both diesel fuels. Physical and chemical tests include visual inspection, distillation character, flash point, kinematic viscosity, cloud point, consistency of water and corrosivity on copperplates. Diesel fuel and diesel fuel with ZnO additives had some minor differences which are most likely caused by measuring errors.

To measure the effects of 10 ppm of ZnO nanoparticles in diesel fuel, we performed engine tests at the Estonian University of life science´s Engine laboratory. To get more reliable results we performed two series of tests with both fuels to make sure we eliminate as much measuring errors as possible. During the engine tests, we measured fuel usage, exhaust gas properties, engine power and burning pressures. All of the tests were done at different loads of 20, 40, 50, 75 and 100%.

During this master´s thesis, we studied the effect of 10 mg/L of ZnO nanoparticles in diesel fuel. According to the measurements that were repeated two times, 10 ppm of ZnO nanoparticles did not have any major effects or improvement. In future research, larger quantities of nanoparticles (20 to 40 mg/L) should be tested to determine whether the addition of ZnO nanoparticles has any positive effects on fuel during the combustions process.

In this research, we found that 10 ppm of ZnO nanoparticles in diesel fuel does not modify the physical and chemical properties of diesel fuel. During the engine test, we found that fuel mixture does not have any major effect on following parameters: lambda, CO, CO_2 and soot. However, hydrocarbons and NO_x have lower values with the addition of 10 mg/L of ZnO nanoparticles in diesel fuel. Calculated parameters indicate that the power and torque are similar, engine efficiency trend lines are also similar according to their test numbers.

Since synthesis with sunflower seeds worked well, future trials should be performed with higher amounts of nanoparticles added to diesel fuel. Tests should be done to determine the quantity of nanoparticles needed to make a visible difference and with further improvement we can obtain better results with these nano-additives.

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ÜLDKOKKUVÕTE

Käesoleva magistritöö eesmärgiks oli uurida nanoosakeste mõju diiselkütusele. Teadustööde põhjal, mis on varasemalt tehtud valiti tsinkoksiidi nanoosakesed, mida sünteesiti kasutades rohelist sünteesi. Rohelist sünteesi kasutati sünteesisimiseks sellepärast, et antud viis on loodussõbralikum kui teised viisid. Antud viis kergitas probleemi, milleks oli missugust taimset saadust kasutada, et saada soovitud tulemus kuna paljud taimed ei ole sobilikud ZnO sünteesimiseks, sest nad on väga rasvased mis omakorda ei lahustu diiselkütuses.

Uurimistöö raames sai uuritud teadustöid mis on tehtud antud teemal. Uurimustöid, mis puudutavad tsinkoksiidi lisamist kütustesse on tehtud mitmeid, ning nende tulemused on olnud positiivsed. Probleem tehtud uurimustega on see, et on lisatud suuremas koguses nanoosakesi, see aga pole finantsiliselt mõistlik.

Nanoosakeste valmistamisel leidsime, et päevalille seemned sobivad väga hästi ZnO nanoosakeste sünteesimiseks. Lõppprodukt on kollakat värvi, tekstuuriliiselt on kuiv ning lahustub hästi diislikütuses ära. Valmistamise käigus proovisime ka Puju seemnetega sünteesida, kuid antud saadus oli õline ning raskesti käideldav. Kuna antud saadus oli väga õline, siis peale 1,5 tundi segamist ei lagunenud kokkuliimitud nanoosakeste tükid ära ning lagenemata suured tükid vajusid katseanuma põhja. Kuna osakesed olid silmaga nähtavad, siis oleks kütusefilter need kinni püüdnud ning need ei oleks mõju avaldanud kütusele.

Teostatud katsete ning mõõtmiste eesmärgiks oli saada võimalikult täpsed tulemused kõikvõimalikest parameetritest, mis puudutavad kütust. Diiselkütusele kui ka lisandiga diiselkütusele tehti füüsikalis- keemilised testid järgmistel parameetritel: Visuaalne inspektsioon, destillatsiooni karakteristikud, leekpunk, kinemaatiline viskoossus, hägustumispunkt, veesisaldus ning korrosiivsus vaskplaadi katsel. Testi tulemusena leiti, et kütustel olid väga väikesed erinevused, mis võivad olla tingitud mõõtmisvigadest.

Eesti Maaülikooli Tehnikainstituudi mootorilaboris viidi läbi mootori testid nii diislikütusega kui ka ZnO lisandiga diislikütusega. Suureima täpsuse saamiseks korrati teste kaks korda, et välistada võimalikult palju mõõtevigu. Mootorikatsetuste käigus mõõdeti kütusekulu, heitgaasides sisalduvate ohtlike ühendite osakaalu, mootori võimsust ning põlemisrõhku. Kõik testid viidi läbi koormuste 20, 40, 50, 75 ja 100%.

Käesoleva magistritöö eesmärgiks oli uurida, missugust mõju avaldab tsinkoksiidi nanoosakesed diislikütuse effektiivsus ning heitgaaside parameetritele. Teostatud mõõtmiste ning katsetuste analüüside järel leiti, et 10mg nanoosakesi ühe liitri kohta ei avalda erilist mõju. Füüsikalis- keemiliste parameetrite testis olid muutused väga väikesed, ning ilmselt põhjustatud mõõtevigadest. Mootori katsetuste käigus leiti, et mõju ei avaldatud järgmistel uurimisobjektile: lambda, CO, CO_2 ning tahmasus. Süsivesinikud ning NO_x väärtused olid võrreldes tavalise diislikütusega madalamad. Arvutuslikkude parameetrite tulemused näitavad, et effektiivvõimsus ning pöördemoment jäävad samadesse vahemikesse. Vastavalt katsenumbritele jäävad ka mootori kasutegurid samasse vahemikku.

Tuleviku uurimustööde jaoks oleks soovitatav kasutada suuremat kogust nanoosakesi kui 10mg liitri kohta. Süntees päevalille seemnetega töötas võrdlemisi hästi, seega võib jätkata nendega sünteesimist. Edaspidine uuring peaks leidma, missugune kogus nanoosakesi avaldaks diiselkütusele kõige rohkem mõju ning missugune on antud mõju.

APPENDIXES

Appendix A. Calculated test results.

A.1 Friction power

	Diesel fuel, kW		Diesel fuel + ZnO, kW	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	0,000229	0,000208	0,000168	0,000193
LOAD 40%	0,000346	0,000285	0,000345	0,000331
LOAD 50%	0,000375	0,000395	0,000346	0,000346
LOAD 75%	0,000393	0,000542	0,000393	0,000379
LOAD 100%	0,000312	0,000557	0,000315	0,000305

A.2 Mechanical Efficiency

	Diesel fuel		Diesel fuel + ZnO	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	0,999795	0,999755	0,999853	0,99981
LOAD 40%	0,999871	0,999891	0,999815	0,999871
LOAD 50%	0,999886	0,999871	0,999892	0,999889
LOAD 75%	0,99992	0,999888	0,999921	0,999921
LOAD 100%	0,999956	0,99992	0,999956	0,999954

A.3 Average indicator pressure

	Diesel fuel		Diesel fuel + ZnO	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	4,960157	5,070157	3,840157	4,530157
LOAD 40%	11,46016	8,040157	11,13016	10,96016
LOAD 50%	13,96016	13,61016	13,06016	13,26016
LOAD 75%	20,65016	20,89016	20,37016	20,15016
LOAD 100%	29,52016	30,02016	29,10016	28,00016

A.4 Indicator power

	Diesel fuel, kW		Diesel fuel + ZnO, kW	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	1,117716	0,847956	1,144147	1,01412
LOAD 40%	2,683278	2,603741	1,859612	2,562844
LOAD 50%	3,285401	3,068667	3,201079	3,116786
LOAD 75%	4,896623	4,829338	4,954425	4,776191
LOAD 100%	7,032773	6,931866	7,153194	6,666693

A.5 Fuel indicator specific consumption

	Diesel fuel, $g(kWh)^{-1}$		Diesel fuel + ZnO, $g(kWh)^{-1}$	
	Test 1.	Test 2.	Test 1.	Test 2.
LOAD 20%	509,9684	739,4248	480,7075	589,6739
LOAD 40%	320,5035	354,1059	473,2171	344,1489
LOAD 50%	307,4206	339,2352	312,3947	328,8644
LOAD 75%	285,9113	302,9401	286,6125	300,4486
LOAD 100%	356,9005	364,4041	359,28	373,0485

LIHTLITSENTS

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